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DEPARTMENT OF AGRICULTURE
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The Protection Forests of the Mississippi River Watershed and Their Part in Flood Prevention

By

E. A. SHERMAN
Associate Forester, Forest Service

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

THE WHITE HOUSE,
Washington, June 1, 1928.

MY DEAR MR. SECRETARY: The President directs me to call your attention to the last provision of section 10 of the act "For the control of floods on the Mississippi River and its tributaries, and for other purposes," approved May 15, 1928, and to request that you ascertain and report to him the extent to and the manner in which the floods in the Mississippi Valley may be controlled by proper forestry practice.

The provision referred to is as follows:

"That the President shall proceed to ascertain through the Secretary of Agriculture and such other agencies as he may deem proper, the extent to and the manner in which the floods in the Mississippi Valley may be controlled by proper forestry practice."

Sincerely yours,

EVERETT SANDERS,
Secretary to the President.

Hon. WILLIAM M. JARDINE,
Secretary of Agriculture.

JUNE 4, 1928.

DEAR MR. PRESIDENT: In compliance with the terms of your letter of June 1, I have the honor to submit herewith an initial report by Associate Forester E. A. Sherman with reference to the relation of forestry to the control of floods in the Mississippi Valley. Some mimeographed copies of this report have been distributed, but, in view of the importance of the subject matter in relation to the general problem of flood control on the Mississippi River, it is believed that the publication and more general distribution of the report would be in conformity with the provision of the act of May 15, 1928.

In compliance with your letter, this department will at once proceed to make such additional studies and to collect such additional data with reference to the relation of proper forestry practice to flood control as prove to be practicable with the present appropriations and personnel of the department and will submit the results of such studies as soon as they take definite form.

Sincerely yours,

W. M. JARDINE, *Secretary.*

The PRESIDENT, *The White House.*

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE PROTECTION FORESTS OF THE MISSISSIPPI RIVER WATERSHED AND THEIR PART IN FLOOD PREVENTION

By E. A. SHERMAN, *Associate Forester, Forest Service*

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FOREWORD

In times past, even before the white man had disturbed the heavy forests of the Mississippi River Basin, floods were known there. With the settlement of the country, forest fires, overcutting, and the abuse of forest and other lands have served to increase the possibility of floods and their severity and the amount and extent of erosion. Forests have a part in the general flood and erosion problem, and it is well that this part should be recognized. It should be emphasized, however, that it is not proposed that forestry should supplant engineering works in flood control but that forestry should supplement whatever means of artificial control may be adopted by engineers.

A program of sound forestry development that will permit the forests of the Mississippi River Basin to exert their greatest influence on the regulation of water flow should include protection of all forest lands against fire, the reforestation of all denuded lands unsuited for agriculture, the extension of proper forest practices to all forest lands, the public ownership of particularly critical areas, the continuance of existing public forests, and placing the public grazing

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lands under management. This program should be supplemented by additional research and investigation of ways and means for the better handling of forest lands as a means of controlling erosion and minimizing floods.

INTRODUCTION

The Mississippi River, from time immemorial and until prevented by artificial barriers, was accustomed every few years to inundate about 30,000 square miles of land. This ancient flood plain, which under levee protection had been developed into a very rich territory, was the scene of the flood of 1927 (fig. 1), the greatest physical disaster in American history. Uncontrollable waters inundated about 18,000 square miles of country and dispossessed about 750,000 people of their homes, some temporarily and some permanently. The property loss was appalling. Fortunately, about 12,000 square miles of the richest portions of the ancient flood plain, as well as the city of New Orleans, were saved by protecting levees.

This disaster removed every doubt that the problem of controlling floods on the Mississippi River is a national responsibility, challenging the best efforts of every public agency. The Forest Service responded by promptly undertaking an investigation of the forests and forest lands of the Mississippi watershed to determine their relation to the great flood problem and the measure in which they might be made to contribute to its solution. The purpose of this publication is to present in broad outline the fruits of that study.

The study did not include the special field of the engineer who seeks to control floods by such structures as levees, spillways, and reservoirs, a field already filled by the Mississippi River Commission and the engineers of the War Department. It did include an investigation of land-surface conditions, particularly in forest regions, with a view to determining if better land use might lower flood crests and reduce flood hazards. The activities recommended as a result of this study are proposed as supplementary to engineering works and in no sense as an alternative.

SCOPE OF STUDY

While this is primarily a report on the protective influence of Mississippi Valley forests, the study upon which it is based necessarily covered surface conditions and land use generally. The starting point was the self-evident fact that the condition of the land surface has a direct influence on the amount of water held and retained by the soil, on the time and rapidity of run-off, and on the silt content of streams contributing to floods, as well as on the volume, velocity, and turbidity of the water itself. It follows that any form of land use which affects the condition of the surface has a direct bearing on the run-off from that land.

One of the important uses of land surface is for the production of forest crops. Land so used constitutes about one-fifth of the total land surface of the basin. The forests usually occupy regions of relatively heavy rainfall, and embrace a large percentage of the areas of roughest topography and greatest elevation. These are, generally speaking, the regions from which run-off is most rapid. Such forest lands doubtless play a relatively larger part in the flood problem than mere area would indicate. Determining what areas

FIG. 1.—TOPOGRAPHY AND FLOOD PLAIN

are now in forests or could advantageously be reforested and estimating their influence on run-off and stream-flow condition come within the field of Forest Service responsibility. This study was limited to that field, excepting as studies of range, pasture, agricultural, and even barren lands were necessary to determine whether or not the extension of forests to lands of some other class was practicable or desirable. The field of this study obviously covered activities and conditions which are factors entering into the flood problem but which do not usually come within the field of the construction engineer's observations and operations.

MISSISSIPPI WATERSHED ALWAYS LARGELY NONFOREST LAND

The Mississippi Basin has always been conspicuous among the great river basins of the world for its large percentage of nonforest land. (See fig. 4, p. 16.) Comparatively speaking, it has always been a lightly forested country. Originally 60 per cent, it is now 80 per cent, nonforest land.

Also floods in the Mississippi have been recorded as far back as history reaches. De la Vega, in describing the difficulties encountered by De Soto's men when, following their leader's death, they determined to build boats and descend the Mississippi, says:

> Then God, our Lord, hindered the work with a mighty flood of the great river, which, at this time, began to come down with an enormous increase of water, which in the beginning overflowed the wide level ground between the river and the cliffs; then little by little it rose to the top of the cliffs. Soon it began to flow over the fields in an immense flood, and as the land was level, without any hills, there was nothing to stop the inundation. The flood was forty days in reaching its greatest height, which was the twentieth of April, and it was a beautiful thing to look upon the sea where there had been fields, for on each side of the river the water extended over twenty leagues of land, and all of this area was navigated by canoes, and nothing was seen but the tops of the tallest trees.

The report on this river submitted in 1861 to the Bureau of Topographic Engineers, War Department, by A. A. Humphreys and H. L. Abbot lists floods as having occurred in 1718, 1735, 1770, 1782, 1785, 1791, 1796, 1799, 1809, 1811, 1813, 1815, 1816, 1823, 1824, 1828, 1838, 1844, 1847, 1849, 1850, 1851, 1858, and 1859. The serious floods of more recent times have been in 1882, 1892, 1897, 1898, 1903, 1907, 1912, 1913, 1916, 1920, 1922, and 1927. The highest recorded stage of water previous to 1927 on the lower portions of the river, was reached by the flood of 1922.

It is difficult to make a fair comparison as to severity, between the later floods and those of earlier times. Before the construction of levees high water every year inundated a considerable area of low country. Naturally, as the levee system has been constructed and the stream confined, the tendency has been for the waters to reach higher and higher levels. Even without any increase in precipitation or run-off, this would be the natural result of excluding the flood waters from lands formerly subject to overflow.

It was early evident that for reliable information on how run-off was being influenced by the presence or absence of forests, a study must be made in detail of the actual source of run-off. The regimen of a stream at any given point is a composite of all factors influencing run-off from the entire area above. Influences constructively beneficial on one drainage unit may be neutralized by destruc-

tive factors on some other contributing stream. Obviously the flood waters as they reach the leveed region are a mixture coming from all kinds of watersheds, some well protected, some poorly, some not at all.

The total area of the Mississippi River Basin, within the United States, including the lands subject to inundation, is 1,231,492 square miles. So vast an area is hard to treat as a unit. Diversity of climate, cover, and human use adds complexity to immensity. Although only about 244,000 square miles of forest lands, or about 20 per cent of the total area, are involved in the problem, these forest lands are distributed throughout the humid portions of the entire basin. Furthermore, the use of forest lands must be coordinated on a practical basis with the use of other kinds of lands adjoining.

Though the source of the great volume of water in the 1927 flood was largely the run-off from heavy and prolonged rainfall in the lower central valley, at the same time a factor to be reckoned with at all times is the contribution which each individual drainage unit may reasonably be expected to make to the main flow at any given time. For a thorough understanding of the problem it was therefore necessary to consider the watershed both in detail and as a unit.

IMPORTANT DATA LACKING

In the course of this study it was found that reliable data essential to accurate determination were in many instances nonexistent. Topographic maps, soil maps, forest maps were too often lacking for important regions.

It seems fundamental to a carefully planned study of land use, covering long-time periods, that there be available accurate data for each of the major tributaries of the river showing annual and periodic run-off and total and periodic volumes of silt content. Dependable data on silt content were woefully lacking. Determinations made many years ago could not be checked against similar data of more recent date because recent measurements had not been made. A complete record of stream-flow measurements and silt determinations at some point below Cairo and on each of the principal tributaries entering the Mississippi River below that point and covering the past four decades would have been of inestimable value in this study. Such records beginning in 1928 would become increasingly valuable from year to year. Regardless of any light the data might throw on the flood problem, it would give a splendid check on the problem of land use and the trend of soil erosion. By means of such records it would be possible at any time to determine whether or not efforts in reforestation, forest protection. contour plowing, and farm terracing were reducing the burden of silt in the river at Cairo or in any of the tributaries under observation. For that reason the absence of such data is noted in this report, and the desirability of securing accurate information of this kind is given a place in the conclusions and recommendations.

MAJOR BASINS OF THE MISSISSIPPI

A systematic investigation of the forested watersheds of the Mississippi Valley and their relation to the floods of that river required a somewhat arbitrary subdivision of the entire region, first into major basins and then into individual drainage units.

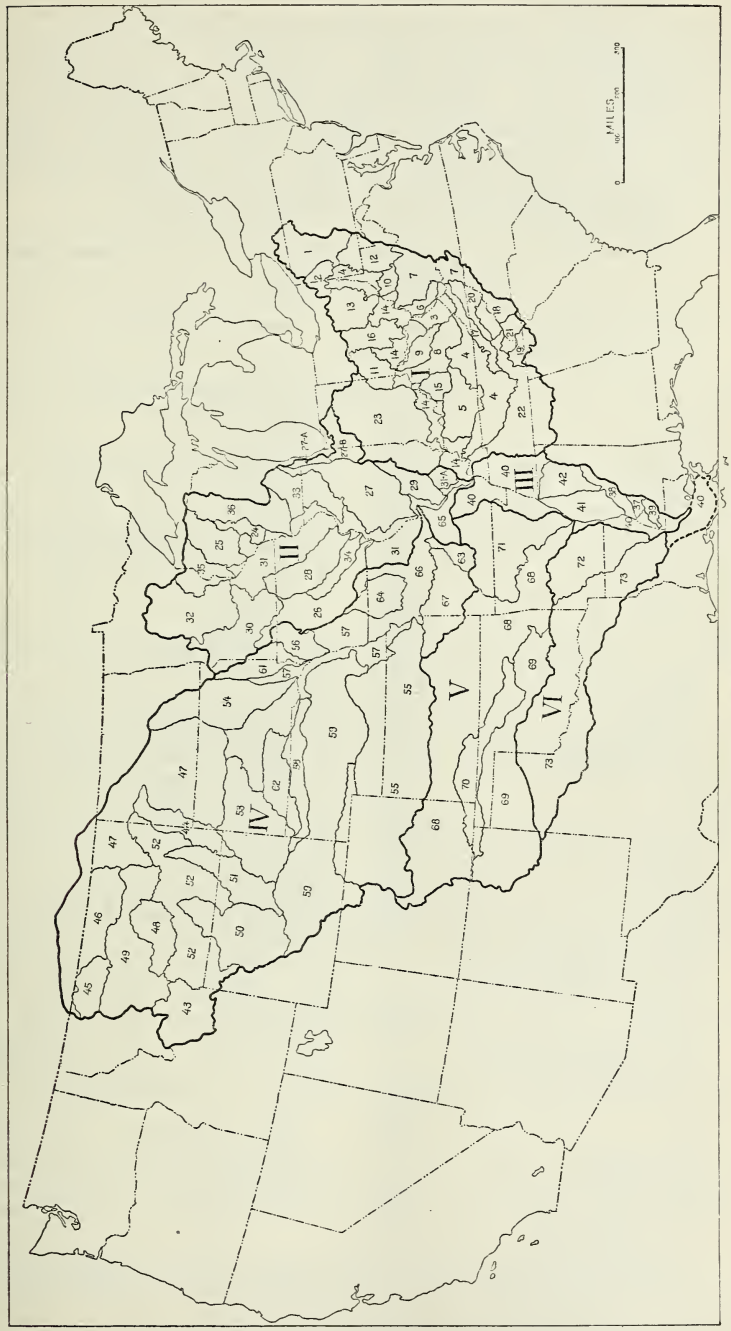

FIG. 2.—Index of major and minor basins

The subdivision into six major basins which was finally adopted for this study is shown in Figure 2. This subdivision appears to be generally followed, with perhaps some minor modifications, by all agencies in studying the Mississippi flood problem. It follows largely the classification used in the report of 1861 by Humphreys and Abbot. These authors, however, treated the St. Francis River and the Yazoo Basin each as distinct major basins. The subdivision of the major basins into principal drainage units used by the Forest Service in making the study, with the areas of each major basin and each drainage unit thereunder, is shown in Table 1.

TABLE 1.—*Mississippi River drainage—Areas of major and minor basins within the United States* [1]

Basin and river number	Area	Basin and river number	Area
	Square miles		*Square miles*
Ohio River:		Lower Mississippi River—Continued.	
1. Allegheny	11,683	41. Yazoo (bottomlands)	7,324
2. Beaver	3,182	42. Yazoo (highlands)	6,496
3. Big Sandy	4,259	Missouri River:	
4. Cumberland	17,939	43. Jefferson-Madison-Gallatin Forks	13,949
5. Green	9,329	44. Little Missouri	9,351
6. Guyandot	2,354	45. Marias	7,079
7. Kanawha	12,303	46. Milk	15,042
8. Kentucky	6,945	47. Missouri (direct—Cheyenne River to mouth of Milk River)	52,703
9. Licking	3,742	48. Musselshell	9,606
10. Little Kanawha	2,382	49. Upper Missouri (above Milk River)	26,827
11. Miami	5,352	Yellowstone	70,172
12. Monongahela	7,339	50. Big Horn	23,057
13. Muskingum	8,052	51. Powder	13,480
14. Ohio (direct)	26,239	52. Yellowstone (direct)	33,635
15. Salt	2,986	53. Cheyenne	25,510
16. Scioto	6,361	54. James	20,715
Tennessee	40,423	55. Kansas	59,710
17. Clinch	4,278	56. Little Sioux and Floyd	5,801
18. French Broad	5,052	57. Missouri (direct—Cheyenne River to Missouri State line)	31,428
19. Hiwassee	2,702	58. Niobrara	11,875
20. Holston	3,826	Platte	89,877
21. Little Tennessee	2,549	59. Platte (main)	65,832
22. Tennessee (direct)	22,016	60. South Fork Platte	24,045
23. Wabash	32,912	61. Sioux	8,212
Upper Mississippi River [2]		62. White (S. Dak.)	10,209
24. Black	2,920	63. Gasconade	3,540
25. Chippewa	9,379	64. Grand	7,831
26. Des Moines	14,184	66. Missouri (direct, in Missouri)	17,232
27. Illinois	21,631	67. Osage	14,967
27a. Des Plaines	1,425	Arkansas—White River:	
27b. Kankakee	5,188	Arkansas	160,664
28. Iowa-Cedar	12,496	68. Arkansas (direct)	95,367
29. Kaskaskia	5,812	69. Canadian	47,552
30. Minnesota	16,264	70. Cimarron	17,745
31. Mississippi (direct—below St. Paul and above junction with Missouri on west side and above junction with Ohio on east side)	34,300	71. White	27,678
31a. Big Muddy	2,402	Red River—Ouachita:	
65. Mississippi (direct—on west side between Missouri and Ohio River junctions)	5,748	72. Ouachita	18,643
32. Mississippi (above St. Paul)	20,449	73. Red	69,548
33. Rock	10,765	SUMMARY BY MAJOR BASINS	
34. Skunk	4,323	Ohio	203,782
35. St. Croix	7,664	Upper Mississippi	186,853
36. Wisconsin	11,903	Lower Mississippi	52,688
Lower Mississippi River: [2]		Missouri	511,636
37. Bayou Tallahala	1,046	Arkansas-White	188,342
38. Big Black	3,559	Red-Ouachita	88,191
39. Homochitto	1,261		
40. Lower Mississippi (direct) [3]	33,002	Total	1,231,492

[1] Based on planimetric measurements of United States Geological Survey maps applied to the actual surveyed areas of the States. Canadian drainage of 12,934 square miles in the Missouri Basin is not included.

[2] The drainage of the Mississippi River proper, excluding the Ohio, Missouri, Arkansas, and Red River Basins, is divided at Cairo, Ill., into upper Mississippi and lower Mississippi.

[3] Includes 5,441 square miles of indeterminate drainage such as the Atchafalaya River and other interconnected waterways in southern Louisiana.

For a proper understanding of the protective influence of the forests of the Mississippi River drainage, their relationship to floods, and their possibilities and potentialities as factors in stream-flow regulation, due consideration must be given to certain well-recognized characteristics of running water and the relationship which forests bear [1] to soil and water conservation. It is commonly stated as a law of physics that the erosive or abrading power of a stream varies as the square of its velocity. For example, if the velocity of a stream is increased 10 times, its erosive power is increased 100 times. It is also commonly stated as an immutable law that the transporting power of water varies as the sixth power of its velocity. For example, if the velocity of a stream is increased ten times, its transporting power is increased 1,000,000 times. Le Conte determined by experimentation that a current having a velocity of 2 miles an hour will move in its channel fragments of stone the size of a hen's egg, weighing about 3 ounces. From this he calculated that a current with a velocity of 20 miles an hour will carry bowlders weighing 100 tons. This is doubtless movement along the bottom of the channel.

It is the understanding of the writer that such so-called "laws" are, owing to certain variable influencing factors, mutable, although the examples cited of the comparative transporting power of river currents furnish a fair criterion of probable results.

FORESTS IN RELATION TO EROSION AND STREAM FLOW

It does not require demonstration or the introduction of scientific data to sustain the self-evident fact that water falling on steep lands tends to run off rapidly. The examples just cited show that erosion is tremendously increased by rapidity of run-off. It follows that for any given type of soil the steepest lands are most subject to erosion. Therefore it is upon steep rough lands that forests as an erosion-preventive factor are most important.

The forest breaks the impact of rainfall and retards the hasty run-off in the following way: (1), its canopy of leaves or needles, with supporting twigs, branches, and trunks, catches the first impact of precipitation and absorbs the first shock of its fall. Instead of beating directly upon the earth the raindrops are shattered and either evaporate or settle slowly in the form of mist, or reassemble and trickle down the trunk and branches, or drip to the ground. The surface of the forest floor frequently has an understory of young growth or shrubs, vines, and other vegetation which may again break the impact of fall. Under all these, at least in the typical virgin forest of the Temperate Zone, is usually an accumula-

[1] LE CONTE, JOSEPH. ELEMENTS OF GEOLOGY. Ed. 5. 667 p. illus. N. Y. 1903. Page 11, "Law of variation of erosive power.—The erosive power of water, or the power of overcoming cohesion, varies as the square of the velocity of the current." Pages 19–20, "By mathematical analysis the law is determined. That is, the transporting power of a current or the weight of the largest fragment it can carry varies as the sixth power of the velocity."

GIBSON, A. H. HYDRAULICS AND ITS APPLICATION. Ed. 3. 801 p. illus. N. Y. 1905. Page 322, "While the erosive power of water varies as the square of its velocity, its transporting power, or the power to move bowlders, etc., which may lie in its path, varies approximately as v^6."

GILLERT, G. K. THE TRANSPORTATION OF DÉBRIS BY RUNNING WATER. U. S. Geological Survey. Professional Paper No. 86. 263 p. illus. 1914. For a careful study, having for its purpose the empirical determination of the relation which the load of solids swept along the bed of a river bears to its velocity and other important factors of control, the reader is referred to this professional paper.

tion of twigs, leaves, needles, moss, and other vegetative growth forming an absorptive layer or carpet of humus often 6 inches or more in depth. Lying as it does, shielded from the wind and sun, this deposit of humus is protected from rapid surface evaporation, while affording most favorable under-surface conditions for the percolation of moisture into the soil.

This layer of humus varies quantitatively and qualitatively according to type, location, and use. Qualitatively the humus from the conifers is more effective as a moisture absorbent than that from hardwoods. Quantitatively it is greatest in the spruce-balsam-white cedar-hemlock type of forest prevalent at the higher elevations or in northern forests and smallest in hardwood regions of the South, where the practice of burning the woods annually is prevalent and where decomposition of vegetable litter is most rapid and complete. Under favorable conditions the layer of humus in a well-managed, well-protected forest of the spruce-balsam-white cedar-hemlock type may be as much as 6 inches deep. Varying with the type of forest, the age class of the stand, the quality and kind of site, and the degree of protection and management, the depth of the humus will shade down from 6 inches to the comparatively small accumulation of a single season, which becomes nil immediately following a fire.

Under ordinary rainfall conditions this humus is capable of absorbing and holding a considerable quantity of water for evaporation, percolation, or transpiration. The amount of moisture thus actually absorbed varies; but a quarter of an inch in depth of rainfall for each inch of depth of humus or leaf litter is known to be conservative. This ratio has been used in all calculations in this report unless otherwise specified. In addition to the moisture absorbed the forest retards or holds in temporary restraint an amount of water often many times as great as the volume actually absorbed. The process of absorption itself is not instantaneous. The forest floor does not expend its full absorptive influence on the first brief shower, but the process continues over a considerable period. Even in entire immersion about 24 hours are required to complete saturation, and under rainfall conditions absorption continues for 48 hours.

While moisture is being absorbed by the mat of humus, the forest-crown cover and forest litter also hold back or retard the run-off of water not actually absorbed. Through such a combination of influences a forest having a good crown cover and a good blanket of humus can be relied upon to absorb and retain for later and more gradual and beneficial transmission a very great part of even an unusually heavy rainfall. Instances are recorded in which a forest with deep humus or leaf litter did not give off any water in the form of surplus run-off even on the steepest slopes after a rainfall of 2.4 to 2.8 inches. This, however, is beyond what can ordinarily be relied upon.

During an extended period of rainfall the quantity of water diverted from run-off by being absorbed by the mat of humus is materially supplemented by the amount of evaporation, percolation, and transpiration taking place during the same period. In addition the forest operates much like a check dam through retarding run-off by mechanical obstruction. The rainfall which is not at once absorbed or permanently impounded sinks into a tangled mass of

accumulated vegetation, fills up its interstices, and slowly searches out through a maze of moss, needles, leaves, twigs, and other vegetative growth, the path of least resistance down the slope. In this way rainfall, which would otherwise reach the nearest brook in a few hours, may be delayed for days or even weeks, may finally reappear in some spring, or may be taken up by some plant and again transmitted to the atmosphere without ever contributing to stream flow.

The forest, its understory of brush, and the blanket covering of humus not only break the impact of precipitation and hold in temporary suspension a considerable volume of water, but their combined influence tends to make the underlying soil and subsoil more receptive to percolation. The soil is loosened by the roots and shielded by brush and trees from being backed by the sun and packed by the tramping of stock. Accretions of humus in the soil itself also increase the permeability and water-retaining capacity of the soil. The mulch covering also keeps the soil moist, so that the forces of absorption as well as gravitation may operate most effectively in helping to transmit to the underlying soil the excess moisture held in temporary captivity.

The forest, the brush, and the humus layer also tend to conserve precipitation in the form of snowfall by protecting the surface of the soil from freezing. Rain falling on ground already solidly frozen, or water from melting snow on frozen ground, runs off as though from a tin roof. On the other hand, even in midwinter after the ground in the open is frozen solidly, moisture from melting snow or rain can usually find its way through open spaces of the coarse top cover of forest litter into the protected layers below where it can be finally taken up by the soil.

The presence of forest cover on a given watershed may under certain conditions increase the run-off from some limited area during the spring flood period. This can happen when an unseasonably warm heavy rain encounters a winter's snow accumulation. There is, of course, a limit to the capacity of forest cover to retain moisture and retard run-off. When this limit is reached a high-water stage follows. Had the forest been cleared away and the bare soil exposed to frost, wind, and sun, most of the winter's snowfall would have been dissipated and the freshet limited in volume largely to the immediate rainfall, little if any of which would have been retained by the frozen ground. The resulting flood, while much more flashy than from a forested watershed, might not reach even as high a stage and would be of very brief duration. However, an increase in flood flow caused by forest protection is the rare exception, and over a large area would be offset by beneficial results from other drainage units. The general tendency of the forest cover is to ameliorate freshet condition, and over any large area the general tendency always prevails—the peak of the flood is not so quickly reached; the run-off is spread over a longer period of time; erosion is reduced; and damage by silting and washing is correspondingly lessened.

In conformity with the known conduct of running streams as stated in the opening paragraph of this section, forests reduce the eroding and transporting power of water by reducing the rapidity of run-off. In addition they are a direct physical obstacle to erosion

because they have large, strong, well-anchored roots which hold soil, subsoil, and rocks firmly in place. A forest with a good understory of brush and a deep layer of humus is undoubtedly the best conservator of soil. Not only is the loss held to the negligible quantity removed by percolation, but actual additions of fertile material are made.

This factor of erosion is exceedingly important in flood-control work. Zon called attention to this fact in the final report of the National Waterways Commission, page 246, saying:

> Erosion has a bearing on the height of flood water in the river, since sediment carried by the rivers and the coarser detritus brought down by mountain streams often increases stream volume to such an extent that the height of the water is raised far beyond the point it would reach if it came free of detritus and sediment.

Not only does the presence of sand and gravel in the water increase the volume of the flood and raise its height, but in addition such abrasive material furnishes teeth to the freshet and enables it to tear up the earth, wear away embankments, and carry off accumulations of soil and other material otherwise safe from the ordinary attacks of flood waters. Erosion fattens as it feeds. Its progress is accelerated by its spoils of victory. The first few cubic yards of sand that enable the stream to wear away the protecting covering of sod from an exposed embankment may expose a thousand cubic yards of similar material to easy capture by the flood waters that follow.

The terrific power of mountain freshets has been pointed out by the famous French engineer Demontsey, who found that one such torrent brought down, after one storm, in 85,000 cubic yards of water, over 221,000 yards of detritus, or more than two and one-half times its own water volume. Those who witnessed the havoc wrought in Pueblo, Colo., by the flood at the headwaters of the Arkansas River, realize the destructive power of liquid mud. The Mississippi River in full-flood flow fortunately does not, even remotely, approach the speed of a mountain torrent. It would not, therefore, be capable of bearing so great a percentage of silt as a swifter stream. It is regretted that this study failed to unearth any reliable figures of recent date on silt content. Figures giving averages over long periods and for varying conditions of flow are obviously no index to actual silt content at flood crest, which is the critical point. Available data seem to indicate that the waters of the Missouri River at full-flood stage may contain as much as 3 per cent foreign matter. No estimate is attempted as to the probable silt content of the recent Mississippi flood at crest. This much, however, is certain—the country would be much richer and much better off if the eroded soil, the amount of which is known to have been great in the aggregate though it may not have made up a large percentage of the flood content, had remained in place undisturbed.

Forests are not the only safeguards against erosion. Any vegetative cover has a tendency to retard run-off and check erosion. A good brush cover or a bluegrass sod is very much better than an open stand of timber which has been heavily grazed or through which a fire has recently run. However, the combination of trees, undergrowth, and forest litter which is secured under adequate fire protection and forest management, is best for critical areas—that is, areas which

owing to natural features are in danger of extensive washing. The canopy is most complete, the humus protection most thorough, and the roots strongest. It is always recommended for permanent protection purposes rather than brush or vines, for the reason that it is of value not only as a conserver of soil but for its wood crop. Tree planting to prevent erosion or for water conservation is, of course, not recommended for fields which can be profitably plowed and cropped without destructive soil washing. Nor are forests recommended for the more moderate slopes with soil which permits the establishment of a good grass cover sufficient to prevent destructive erosion and where the economic value of such cover equals or exceeds that of the forest. A good grass cover, where it can be secured and maintained, is an excellent safeguard against erosion except on the steepest slopes. As a factor in water storage or regulation, however, it does not compare with a well-managed forest.

The question of whether or not total run-off is increased or diminished by the presence of forests is one which does not admit of a categorical answer. The character of soil, the gradient, and the time, duration, quantity, and form of precipitation, as well as the character of the cover, all enter into the equation. Obviously, the ratio of total run-off to precipitation will be greatest where the slope is steepest, the soil most impervious, and vegetation most scanty. In such a case the maximum run-off occurs at once.

Usually immediate run-off is not desirable. Ideal conditions are usually found in regularity of flow, regularity at least during the period of beneficial use and sufficient to avoid an embarrassing surplus. In some cases, such as on a watershed which is a source of water supply for irrigation, power, or domestic use, the maximum sustained volume of run-off is desirable—the greater the supply the larger the acreage irrigated, the greater the power development, or the more generous the domestic supply.

Trees consume water. A rapidly growing forest may during the year consume and transmit into the air a volume of water equivalent in depth to 12 inches over its entire area. On rocky slopes, upon which through generations the forest has spread its carpet of humus to hold in its store of moisture and to help secrete water in crevices where it may be reached by the searching tree roots and used in plant growth, the forest obviously uses moisture which otherwise would have contributed to immediate run-off. But this water is only used; not destroyed. In the atmosphere it is again available for precipitation.

The flood problem is measured by the volume of run-off. Only a part of the total precipitation on any watershed ever appears as run-off. Necessarily that part of precipitation which passes into the atmosphere either by evaporation or transpiration can not appear in stream-flow measurements without again being deposited in some form of precipitation. On the other hand that part which passes into the soil as percolation must eventually appear as run-off unless evaporated or taken up in plant growth.

In the study of the relation of forests to stream flow, an important fact to keep in mind is the wide difference between the total precipitation and total run-off of any watershed. Also the fact that the ratio of the latter to the former varies widely for different watersheds. Something very important happens after the water reaches

the earth but before it reaches the river. This "something" is the result of the working of three natural phenomena, transpiration, percolation, and evaporation. The two first do not greatly influence the volume of water after it once reaches a stream in the form of run-off, but the last continues its pursuit of moisture even to the sea itself. Transpiration and percolation are greatly stimulated by plant growth. This applies to forests, particularly as to percolation. Forests retard evaporation from the soil under certain conditions, but this is more than offset, so far as immediate run-off is concerned, by transpiration and percolation.

If the value of forests as stream-flow regulators and flood-preventive factors were determined by the ratio of their water-storage capacity to the total annual precipitation, such value would be relatively very small. However, such a comparison does not give a rational basis of measurement. Floods are created only by actual run-off. Therefore, the ratio of storage to run-off is a better index of flood-prevention service. [It seems desirable to illustrate the importance of this point by calling attention, out of its otherwise natural order, to the fact that of the total precipitation falling annually on the 511,636 square miles of the Missouri River watershed only 10 or 15 per cent (authorities differ, but 15 per cent is probably the better figure) ever reaches the Mississippi. The other 85 or 90 per cent is transmitted to the atmosphere by transpiration or evaporation, minus such minor quantities as may possibly be retained by some chemical process or combination.]

It is this remaining percentage which appears as run-off that contributes to the flood problem, and it is this remnant of the total for each watershed that may be in part regulated or controlled by well-managed protection forests. The ratio of run-off to precipitation is much larger for the other major basins of the Mississippi system than for the Missouri (primarily because both are higher—the spread between the two does not vary so much under similar climatic conditions), but in every case evaporation and transpiration are important factors in disposing of the total supply of water. The average run-off for the various parts of the Mississippi Valley region is shown graphically by Figure 3.

The wide difference between total precipitation and total run-off from the Missouri watershed is extremely interesting. Since that watershed is neither a lake which is increasing in size nor a shrinking desert, it must be that the 10 or 15 per cent of precipitation which the river carries in annual run-off balances the watershed's moisture account with outside sources. This fact, together with the known fact that plant life draws from the soil and returns to the atmosphere for reprecipitation considerable quantities of moisture which would otherwise have contributed directly to stream flow, suggests the possibility of increasing precipitation by encouraging vegetative growth. By irrigation, which means the recapture of moisture from run-off and its return to the soil for redispersion through evaporation, transpiration, and percolation, water may be used repeatedly. It is indestructible. By such methods of recapture and use over a period of years the water capital of a region may be greatly increased. These possibilities and their climatic consequences open a field of speculation which, however attractive, is beyond the scope of this circular.

PROTECTION FORESTS, A PUBLIC NECESSITY

The influence of forests in retarding run-off and thus diminishing the destructive power of floods, and the value of forests in binding soils and preventing erosion have resulted in many forest areas in civilized nations being established as protection forests and placed under public control. These are largely in mountainous regions where, by reason of the nature of soil, topography, and climate, conditions causing accelerated run-off are most critical and most apt to result from ordinary private use of the land surface.

The use to which any forest area is put has a direct bearing upon its effectiveness as a protection forest. Its protective influence may be injured by the character, extent, or method of timber cutting,

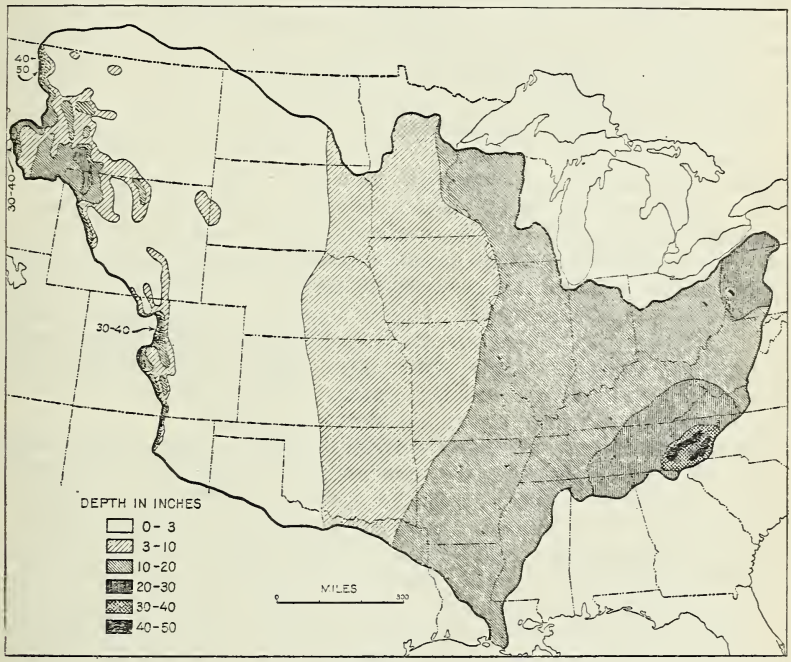

FIG. 3.—Average annual run-off

by the season and intensity of grazing, or by any other kind of use. The private owner is interested in using the forest to produce revenue rather than public benefits. For this reason, public ownership has been found to be the only practicable means of securing the highest use of forests where the protective function is so important that other uses, such as grazing and timber cutting, must be subordinated to protection.

Self-preservation requires that the public step in and acquire rough broken lands where the destruction of forests or failure to maintain good forest conditions menaces interests of far-reaching importance. From the standpoint of a future national timber supply to be derived from our great commercial forests, the public interest may be safeguarded by Federal cooperation in fire control and

leadership in forest management. The private incentive of revenue production will be served by securing the maximum productivity of the lands. Thus far self-interest and public interest travel one road. But where protective values are outstanding, as they are in most mountainous regions, a large measure of public ownership is a public necessity.

Public ownership of nonagricultural forest land on important watersheds is the logical outcome of the free play and development of natural economic laws and forces. The private owner of forest land in steep, rough regions can not be expected to manage his property for the public benefit when that means loss of revenue or increased expense. Conversely, the owner of properties which may be injured by the misuse of such land can not safely rely upon the owner of the forest to give other lands contributory protection. Consequently, where widely scattered but important interests may be jeopardized by unwise use of land, the only fair and safe course is for the public to step in and take charge of the key property under terms and conditions fair to the original owner.

France, Germany, Switzerland, Austria, and Japan have each recognized the special function of the protection forest, and each places such areas under public control. This principle has been carried farthest in Japan, where, owing to the mountainous character of the country, it was most urgently needed. In that little nation a total of 4,534,335 acres in 353,549 parcels has been placed under public control as protection forests. Protection forests in Japan are established against soil erosion, for water supply, against sand shifting, against wind, against tides, against floods, against avalanches, against rolling stones, for fisheries, for public health, for guiding navigators, and for scenery. However, over 90 per cent of the total area comes within the first two classes.

Protection forests are also maintained by our own Government. The act of 1897 (30 Stat., 11) authorized the President to establish public forests "for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States." The same principle was recognized by the Weeks law, passed by Congress March 1, 1911 (36 Stat., 961). Under this act there had been expended by the Federal Government, under the direction of the National Forest Reservation Commission, up to June 30, 1927, a total of $14,065,260.87 in the purchase of 2,892,721 acres of forest land for the protection of navigable streams. These lands lie in the White, Allegheny, Appalachian, Ozark, and Ouachita Mountains. They are in 19 purchase units located in 13 States.

In the application of the protection-forest principle the Forest Service has proceeded upon the theory that under our form of government the duty and responsibility of establishing public forests and regulating their use should rest first upon that public agency nearest to the problem, provided that agency is directly concerned in its solution, whether city, county, State, or Nation. The Federal Government should not step in if the local governing authority nearer the problem is willing and able to meet the public need. The same principle naturally applies all the way down the line. A town

organization would not give an individual protection which he is able to provide by labor with his own hands on his own lands.

This principle has been kept in mind in this study. On Figure 6 are outlined many areas which are in urgent need of being given the status of public protection forests, also areas within which it is known that there are lands which should be given such status. No attempt has been made at this time to determine the respective fields of local, State, and Federal activities in providing protection forests. As a principle of government it is considered desirable from a national standpoint for cities, counties, and States to shoulder this responsibility so far as they are able to do so without undue hardship. Along with this principle it has also been necessary to give due consideration to the fact that often the community nearest a protection forest is not so vitally concerned as others farther removed. In such cases it would be unreasonable and unjust to expect the local taxpayer to finance an activity for the primary purpose of benefiting other regions. In some cases Federal help seems to be the only reasonable solution because of large areas and heavy expense. In such cases, where the State has already signified its approval of Federal participation, prompt action by the Federal Government is recommended.

FORESTS OF THE MISSISSIPPI VALLEY

The forest area of the Mississippi Valley has undergone great changes since the advent of the white man.[2] His form of civilization has made tremendous inroads into the virgin stands which greeted the arrival of our pioneer ancestors. The first great inroad was made in the clearing of lands for cultivation in the Ohio River drainage. This activity swept through the valleys of the Ohio and its tributaries, spread out over the rich rolling uplands, and emerged on the still more inviting prairies of the North and West. So strong is habit that the rolling timbered hills of Missouri were cleared and cropped before the prairie lands of Iowa were generally brought under cultivation.

The second great drain on the virgin-forest resources of the Mississippi Basin was lumbering. This started in rafting and floating logs and other forest products down the river to New Orleans for local and foreign trade; but got its greatest impetus when the pine, spruce, and hemlock forests of Wisconsin and Minnesota were drawn upon for the settlement and development of the great interior prairie of the Middle West. Like the clearing for agriculture, lumbering spread by widening circles into every region accessible to the growing country's demand. It reached into the great hardwood regions south of the Ohio River and sought new fields in Missouri, Arkansas, eastern Texas, Louisiana, and western Mississippi.

The process of lumbering, necessary in itself as an incident to settlement, growth, and industrial development, has unfortunately been almost universally followed, if not actually accompanied, by the forest's worst enemy, fire. This has not only taken a toll in timber probably equal in volume to that removed either in lumbering or agricultural clearings, but has in addition still more vitally

[2] Evidences of these changes may be seen by comparing Figs. 4 and 5

affected the protective value of the forests and the future timber supplies by injury to the site, impoverishment of the soil, destruction of young growth, and the prevention of forest regeneration. Even in regions where these injurious effects are most evident, forest fires are still frequently considered an incident natural to the woods.

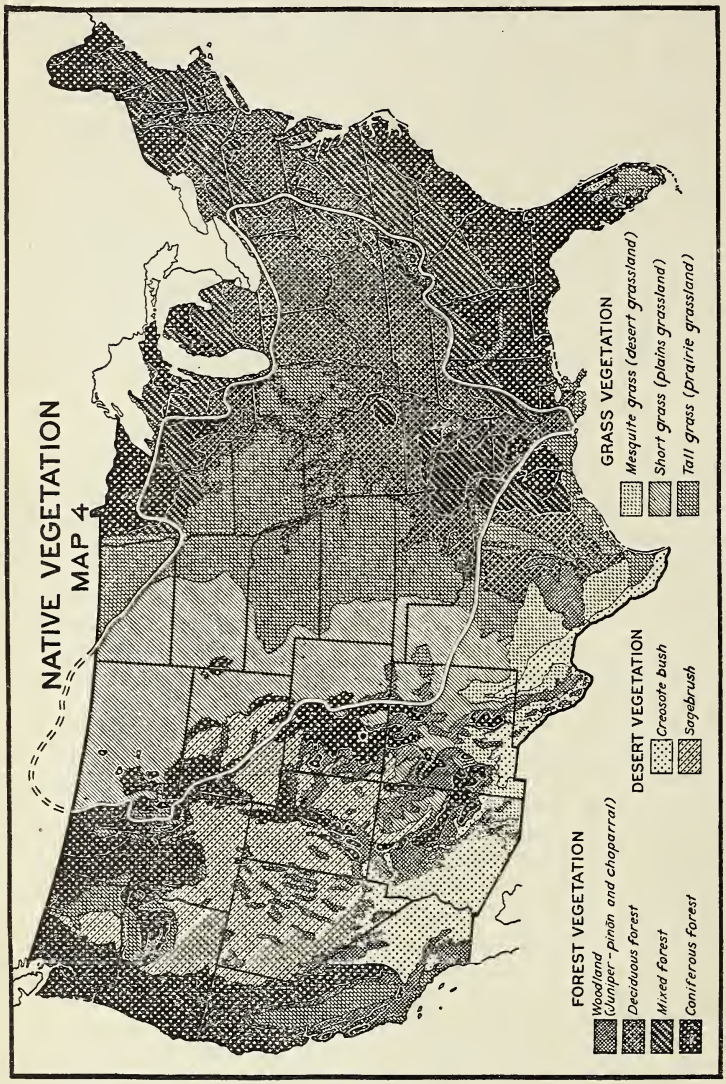

FIG. 4.—Natural vegetation

Considered entirely as a virgin area, the Mississippi Valley, even before the coming of the white man, was never what could be classified as a well-forested watershed. Not more than 40 per cent, or about 500,000 square miles, out of a total of 1,231,492 square miles, was in forests or woodlands at the time of discovery and settlement.

(Fig. 4.) The fact that floods were characteristic of the Mississippi River from time immemorial need not disturb the champion of forests as a factor tending to regulate stream flow. If that fact has

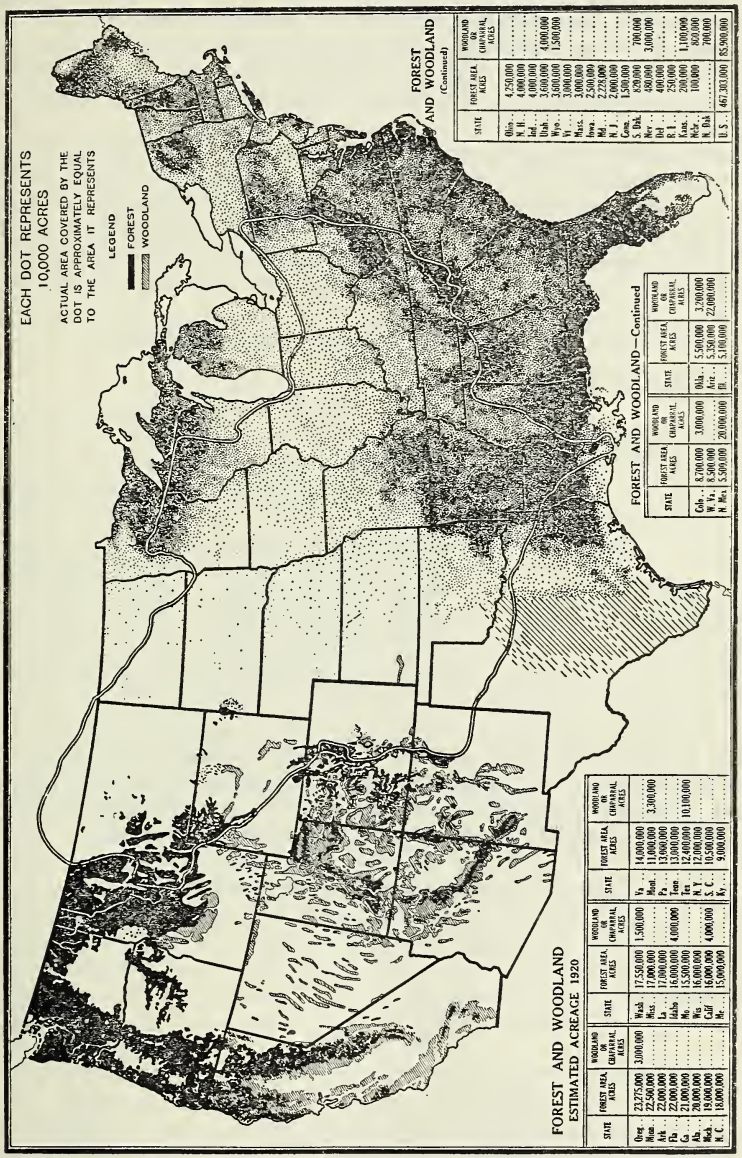

Fig. 5.—Forest-land density

any significance it is evidence tending to associate floods with a non-forested area, since even in De Soto's time floods occurred and 60 per cent of the watershed was then without forest cover. The primary cause of that flood, as well as the flood of 1927, was unusually heavy

rainfall, the effect of which the 40 per cent of forest in De Soto's time and 20 per cent of forest in our own day might somewhat ameliorate but could not prevent.

Now only 20 per cent of the basin is in forests of any kind. Even this includes a considerable acreage of denuded land and for the most part is in an unsatisfactory condition as to forest cover and forest floor. (Fig. 5.) Only a small percentage of the land in forest is in satisfactory condition for timber production or watershed protection.

Table 2 shows for each of the six major basins of the Mississippi Valley the total area, the area originally in forest, and the present forest area including farm wood lots and nonrestocking forest land, with area comparisons in percentages. The last column gives for each basin the percentage of total area deforested. The "total" line gives the same information for the Mississippi drainage as a whole.

TABLE 2.—*Forest lands of the Mississippi drainage*

Basin	Total area	Forest land (including wood lots and idle lands)		Percentage of basin areas		
		Original	Present	Original	Present	Decrease
	Square miles	*Square miles*	*Square miles*	*Per cent*	*Per cent*	*Per cent*
Ohio	203,782	186,000	68,000	91	33	58
Upper Mississippi	186,853	108,000	52,000	58	28	30
Lower Mississippi	52,688	51,000	29,000	97	55	42
Missouri	511,636	49,000	31,000	10	6	4
Arkansas—White	188,342	59,000	35,000	31	19	12
Red—Ouachita	88,191	44,000	29,000	50	33	17
Total	1,231,492	497,000	244,000	40	20	20

Table 3 gives the progress of forest destruction by basins. It shows the number of square miles of original forest cleared and devoted to farm, pasture, or other uses and the percentage of the original forest area of the basin which this area represents:

TABLE 3.—*Reduction of original forest lands*

Basin	Reductions		Basin	Reductions	
	Area	Percentage of original forest		Area	Percentage of original forest
	Square miles	*Per cent*		*Square miles*	*Per cent*
Ohio	118,000	63	Arkansas-White	24,000	41
Upper Mississippi	56,000	52	Red-Ouachita	15,000	34
Lower Mississippi	22,000	43			
Missouri	18,000	37	Total	253,000	51

The estimate of a total of 244,000 square miles of forest lands in the Mississippi Basin includes not only the commercial forests, farm woodlands, and other timberlands, but also includes about 35,000

square miles of so-called "idle" or "waste" lands. These are areas once timbered or adapted to timber growing which have been so denuded by overcutting and repeated fires that they are no longer capable of restocking themselves with valuable timber in commercial quantities. Hence they are of such low value that no one will make an effort to protect them. Lacking timber cover and continually robbed by fire of surface protection, they offer only low resistance to erosion.

About 10,000 square miles of such "idle" or "waste" land is included within the total of 115,000 square miles of woodlands belonging in farm ownership. The farm woodlands are chiefly in regions devoted primarily to agriculture.

The 129,000 square miles of forest land not in farm wood lots are in the regions where soil and topography generally are more favorable for forest growth than for farm use. Unfortunately only about 104,000 square miles are occupied by tree growth of commercial species, 25,000 square miles falling in the "idle" or "waste" class.

HOW THE WATERSHED FORESTS WERE STUDIED

It was to the 244,000 square miles of forest land remaining on the Mississippi watershed, some timbered and some idle or waste, scattered throughout the 6 major basins and 73 individual drainage units, that this study was directed. It is desirable to make clear at this point that the value of a forest in preventing erosion and regulating stream flow is not directly proportional to the volume of timber on any given area. It is influenced by other factors, such as density of cover, amount and character of undergrowth, and depth of humus accumulation. A mature forest in open stand may support a large amount of merchantable saw timber and yet because of overgrazing or repeated ground fires be so devoid of undergrowth and leaf litter as to be rated very low from a protection standpoint. On the other hand, a watershed may be very well protected by a young or scrubby growth or by thickets of inferior species by reason of the density of its canopy and the depth of litter accumulation.

Previous general studies of the forests of different regions of the United States have been made principally for the purpose of determining the value of the forests as sources of lumber or other wood products or of estimating their timber-producing possibilities. But the flood problem required a study of forest areas markedly differing from anything ever before undertaken on so large a scale. The primary purpose was to find out, if possible, to what extent our forests may be relied upon to help reduce floods and flood damage on the Mississippi.

This required at the very outset a study of the forests and forest lands of the basin to determine the extent and location of areas having important protective significance as distinguished from areas from which run-off was not materially influenced by the presence or absence of forest cover.

CRITICAL AREAS[3]

In the plan of this study an endeavor was made first to localize the source of watershed trouble so far as was found practicable, in

[3] See Fig. 6 and Table 7.

order that effort might not be wasted, and that attention might be focused on the "critical areas" rather than diverted to others of less importance.

To be of any substantial or permanent value it was evident that the classification of the areas could not be based entirely upon the immediate efficiency of each watershed. It was obviously just as important in the long run to prevent a good protection forest from being injured as to restore the efficiency of a similar area which had already been injured. Just as important and much cheaper and easier.

There were therefore placed in the "critical areas" class all forest lands found to be of such character, by reason of factors of soil, slope, and precipitation, that to prevent flashy run-off or destructive

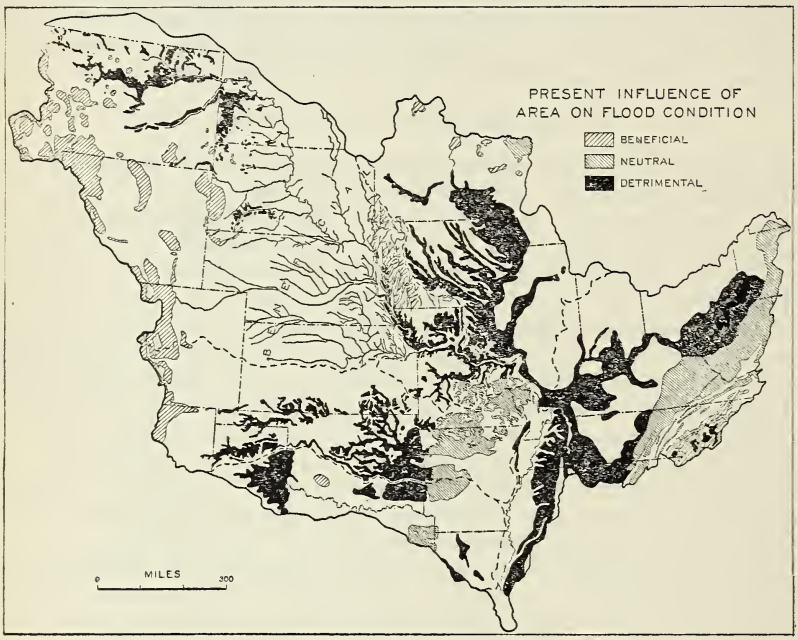

FIG. 6.—Critical erosion areas

erosion the maintenance of a good forest cover was necessary as proved by the results of forest destruction on similar land. It was upon the areas so classified as "critical areas" that this study finally centered. Under this general designation of "critical areas" two general regions not falling in the class of forest lands were finally included. These are the Bad Lands and "the Breaks."

HOW DETERMINED

The determination of "critical areas" involved the consideration of many complex and conflicting factors. While the three main factors which determined the final classification (soil characteristics, physiography, and precipitation) are relatively constant for each part of a drainage unit, they vary for different parts of the unit.

Furthermore, each factor is exceedingly complex. For example, an average precipitation of 40 inches annually in the form of an occasional torrential rain will have a very different effect from the same total amount of precipitation in many gentle rains well distributed throughout the year. Any system of measurement based upon factors so variable is obviously not infallible. At the same time it has furnished the Forest Service with a substantial background of information which, when checked by run-off conditions on the ground, is reasonably accurate. At least it gives different examiners in different regions common standards of measurement and makes comparisons possible. Faulty as this method may be, wide diversity of conditions required the adoption of some uniform method of rating watersheds in order to make possible the summations and comparisons absolutely essential to any real conception of actual conditions on such a large area.

By means of the rating system adopted Figure 6 now gives for the first time a graphic presentation of the areas where the maintenance of good forest cover is believed to have an important relationship to flood control.

The location of "critical areas" having been determined, a further classification was made according to present conditions. Those which were not the source of heavy deposits of silt or flashy run-off were classified as "beneficial." Those which had seriously deteriorated but were apparently in a static condition, if not actually improving, were classified as "neutral." Where deterioration was active the areas were classified as "detrimental."

HAS DEFORESTATION INCREASED THE SEVERITY OF MISSISSIPPI FLOODS?

It has not been possible, within the limited time available for this study, to determine quantitatively to what extent forest depletion has contributed to the Mississippi floods. It has seemed more important to determine how and to what extent forests may contribute to flood prevention. It is sometimes claimed that there has been no marked change in the Mississippi flood situation due to deforestation or any other cause. This study has not undertaken either to prove or disprove such a theory. It does, however, seem well to call attention to certain facts. (1) By the construction of dams at the outlets of certain lakes, Lake Winnibigoshish and others, reservoirs have been established at the headwaters of the Mississippi constituting what is said to be the greatest water-impounding system in the world. (2) There is now under irrigation in the Mississippi Valley, according to the 1920 census, a total of 5,005,577 acres of arid land.

The impounding capacity of the lake reservoirs at the headwaters of the Mississippi is reported to be slightly in excess of 95,000,000,000 cubic feet. A reasonable estimate of the average amount of water used in irrigating arid lands on the Mississippi watershed is 24 inches annually. The total amount of water diverted from stream flow and absorbed by the reported acreage of irrigated land each year is therefore more than 435,000,000,000 cubic feet, or more than four and one-half times the total capacity of the great reservoir system in Minnesota. Of course not all of this water is consumed by evaporation and plant growth. A considerable part eventually

reappears in springs elsewhere and returns to stream flow, but such return is a gradual process. These are only two outstanding examples of the control of water in the Mississippi Valley out of hundreds that have taken place during the past 40 years. If, therefore, there has not been a marked change in the flow of the river during this period the only possible explanation seems to be that such works beneficial to the stability of stream flow have been offset by other factors of equal power, but working in a detrimental direction.

STUDY REQUIRED CONSIDERATION OF ALTERNATIVE USES OF FOREST LAND

The study of the protective influence of forests in the Mississippi Valley and of the contribution that effective forest protection, necessary reforestation, and the productive use of land for forest crops, may make to flood control, proved to the men engaged in this work that, broadly spreaking, the problem was one of the wise use of land. It was found necessary not only to study the areas which are in forests and to determine whether or not they were doing their share toward water and soil conservation, but in many cases it seemed even more necessary to study lands which, although not now in forests, should be.

It may as well be stated at this time that undoubtedly the greatest burden of silt and freshet run-off contributed to the Mississippi River comes not from forest land but from farm lands which are being unwisely used. The reports on the 6 major basins and the individual reports on the 73 drainage units uniformly testify to the general fact. Not only is the silt and run-off greater from the agricultural regions as a whole than from the forest regions—it could hardly be otherwise from a great basin only 20 per cent in area timbered—but greater in proportion to area.

Again it should be made clear that it is not the original lumbering operations which have mainly caused soil impoverishment, erosion, and floods, but the repeated fires which have usually followed such operations. Nature is a great physician. If given a reasonable opportunity she displays marvelous skill and promptness in curing many ailments. The forest on a hillside may be removed by fire or logging operations. The first year following such destruction or utilization the snowfall goes off in a torrential rush, which makes a gulley of every road, log slide or wheel track. But in a few years, at the most 5 or 6 in relatively humid regions or 15 or 20 in semiarid regions, if there have not been repeated fires, nature will have stopped destructive erosion. But, unfortunately, the curative process of nature is usually defeated by the destructive process of burning the woods. Erosion may be stopped in a few years, but it takes much longer to rebuild the mat of humus to its maximum storage capacity and restore the diminished springs to their original flow. The odds against nature are usually so great that such results can not be expected without effective fire protection and intelligent forest management.

CLASSIFICATION OF FORESTS

For the purposes of this circular, the forest lands of the Mississippi Valley have been divided into three classes based directly on

ownerhip—but ownership largely as influenced by use. The three classes are as follows:

1. Commercial forests privately owned.
2. Farm woodlands and forest lands within regions where agricultural interests are generally dominant.
3. National forests and national parks and the unreserved timbered portions of the public domain.

COMMERCIAL FORESTS

Lands classed as commercial forests, which in some regions are often given the general designation "lumber woods," embrace the major lumber regions of the valley and have in the aggregate a total area of 108,000 square miles, including cut-over and waste lands similar in character and location. They are in private or corporate ownership and are the source of most of the lumber produced in the valley. Generally speaking, they are of negligible value for farm-crop production chiefly because of soil or topographic features. They are broadly grouped under the following subdivisions: 1. "Lumber woods" of Minnesota and Wisconsin; 2. Hardwood region of Ohio Basin; 3. Bottom-land hardwoods of Mississippi Delta; 4. Southern pine region of Louisiana, Mississippi, and Arkansas, with adjoining upland hardwoods.

Each of the foregoing regions will be discussed separately. One important feature common to all is the fire hazard and the injury which has resulted from the ravages of fire. Each region has its season of fire danger. In each region fire control is a major factor in forest perpetuation. Yet in each region this fact has been given little consideration by the landowner until recently unless merchantable stands of saw timber, improvements, equipment, or saw logs have been threatened.

Section 2 of the Weeks law of March 1, 1911, recognized the importance of forests from a stream-protection standpoint and authorized Federal cooperation with the States in protecting from fire the forested watersheds of navigable streams. This encouraged States and private owners in many regions to undertake systematic fire protection. The Clarke-McNary law broadened the basic act, with the result that the Federal Government is now cooperating in organized fire protection with 20 States lying wholly or partly within the Mississippi Valley.

The Clarke-McNary law was based upon the theory that fair division of the costs of protecting forest lands from destruction was 50-50 as between the private owner and the public; that one-half of the public share should be assumed by the Federal Government and one-half by the local powers, and that the work should be directed by State authority.

Under this law progress is being made in protecting the forests of the Mississippi Valley as well as elsewhere, but not as rapidly as could be wished.

On Figure 7 the area in the Mississippi watershed now covered by cooperative fire protection is shown graphically. By comparing this with Figure 6, showing the areas which are critical from a flood standpoint, it will be seen that the blanket of protection falls far

short of covering the areas of fire hazard. However, the trouble lies not so much in the shortness of the protection blanket as in its thinness. The organization is far from being adequate to cope with the danger. This situation is shown in detail by Table 4, which gives for each State the area in the Mississippi drainage requiring forest protection, the estimated cost of adequate protection, and the extent to which the Federal Government is meeting its 25 per cent of such estimated cost, also the extent to which the private owners and States are meeting their 75 per cent of the estimated cost of adequate protection.

TABLE 4.—*Fire-control cooperation, under section 2 of Clark-McNary law, with States and private owners in the Mississippi Valley*[1]

State	Approximate area of State and private forest land in need of protection	Estimated cost of protection	Federal share of cost, 25 per cent of whole	Federal funds available fiscal year 1928	Extent to which Federal Government is meeting responsibility	State funds available fiscal year 1928	State share of cost, 75 per cent of whole	Extent to which States are meeting responsibility
	Acres	*Dollars*	*Dollars*	*Dollars*	*Per cent*	*Dollars*	*Dollars*	*Per cent*
Alabama	2,000,000	23,140	5,785	1,968	34.0	2,282	17,355	13.1
Georgia	341,400	5,500	1,375	430	31.3	593	4,125	14.4
Kentucky	9,000,000	225,000	56,250	14,404	25.6	14,404	168,750	8.5
Louisiana	8,510,000	203,700	50,925	19,400	38.1	57,036	152,775	37.3
Maryland	50,000	2,856	714	280	39.2	1,400	2,142	65.4
Minnesota	9,000,000	132,980	33,245	21,715	65.3	102,059	99,735	102.3
Mississippi	4,000,000	90,000	22,500	7,910	35.2	13,760	67,500	20.4
Missouri	10,000,000	260,000	65,000	11,000	16.9	11,000	195,000	5.6
Montana	1,000,000	17,680	4,420	1,685	38.1	5,150	13,260	38.8
New York	400,000	27,000	6,750	2,890	42.8	14,855	20,250	73.4
North Carolina	600,000	16,000	4,000	1,368	34.2	1,700	12,000	14.2
Ohio	1,100,000	27,800	6,950	2,913	41.9	14,623	20,850	70.1
Oklahoma	5,000,000	160,000	40,000	13,710	34.3	14,670	120,000	12.2
Pennsylvania	3,600,000	104,960	26,240	10,035	38.2	58,100	78,720	73.8
South Dakota	50,000	1,500	375	375	100.0	7,235	1,125	643.1
Tennessee	10,000,000	250,000	62,500	21,250	34.0	21,250	187,500	11.3
Texas	300,000	5,588	1,397	477	34.1	496	4,191	11.8
Virginia	1,000,000	30,072	7,518	2,560	34.0	2,560	22,554	11.4
West Virginia	5,850,000	140,500	35,125	13,290	37.8	44,388	105,375	42.1
Wisconsin	12,000,000	232,400	58,100	23,100	39.8	86,856	174,300	49.8
Total	83,801,400	1,956,676	489,169	170,760	34.9	474,417	1,467,507	32.3

[1] Total funds available, fiscal year 1928, $645,177; additional sum required to provide adequate protection $1,311,499 a year, of which the United States Government should provide an additional $318,409 and the private owners and States should provide an additional $993,090.

It will be seen from Table 4 that at the present time the protection given the forests of the Mississippi Valley is about one-third adequate. Obviously we can not expect these forests to give satisfactory protection from erosion to the critical areas and from flood to the lowlands unless the forests themselves are adequately protected. After the study which Congress has already given this part of the forest problem, it does not appear necessary to extend the discussion in this circular further than to say that the reports on each individual drainage unit constituting the great basin of the Mississippi indicate that forest fires everywhere play a large part in forest depletion. Even where the standing timber is not consumed or killed, repeated fires are preventing the accumulation of normal undergrowth, small trees, and depth of humus. Fires are in every region reducing the storage capacity of the privately owned com-

mercial forests, and freshet run-off accompanied by unnecessary erosion results. No matter what other steps are proposed, effective fire control is needed in all the forest regions on the Mississippi watershed. It is the first step in developing the possibilities of forests for flood prevention.

LUMBER WOODS OF MINNESOTA AND OTHER LAKE STATES

The lumber woods of Minnesota and the other Lake States is a region of conifers or mixed conifers and northern hardwoods, such as beech, birch, and maple. Its southern boundary runs from east to west as follows: From Kilburn northwest to Black River Falls, thence to Eau Claire and St. Croix Falls, Wis., or Taylors Falls, Minn., thence west to Rush City, thence to Milaca, thence to Little Falls and Wadena, and thence north to Itasca Lake.

This was the region of the great northern white pine and Norway pine forests on the sandy plains. The swamps contained black spruce, northern white cedar, tamarack, and balsam fir. Only a negligible amount of virgin forest remains. Fortunately the watershed problem in this region is not generally critical. Much of the area has sandy soil which, in this comparatively level country, absorbs precipitation promptly and is not subject to erosion. In addition, swamps and innumerable lakes combine to make the whole region a natural storage reservoir. This has been supplemented by a system of six great reservoirs constructed and operated by the United States Engineer Corps. The total capacity of this system, which embraces Lakes Winnibigoshish, Leech, Pokegama, Pine Sandy, and Gull, is 95,268,100,000 cubic feet.

Despite the fact that these lands are in an exceedingly unsatisfactory condition from the standpoint of timber production, they are not generally a menace to the watershed. The condition of the soil, the topography, and the numerous lakes which act as storage reservoirs and settling basins, all combine to furnish a very regular flow of water unusually free from sediment. This statement can be made for the Mississippi River as a whole as far south as the outlet of Lake Pepin, which acts at its last general settling basin.

One exception is noted at the head of the Wisconsin River where, owing to the character of topography, nature of soils, and climate, the preservation of forest cover is of public importance. An examination of this general region has been made by the secretary of the National Forest Reservation Commission in furtherance of the Weeks law, and an area of about 250,000 acres of rough land with innumerable lakes has been found to have great possibilities as a protection forest under public ownership or control. About 100,000 acres of the area lie on the Mississippi drainage and could probably be acquired at an average price of about $2.50 per acre. This area appears to be the one portion of the lumber-woods region of the Lake States the control of which for forestry purposes would have any material bearing on the flood situation.

It may, and undoubtedly will, be necessary to establish other public forests in this part of the Mississippi Valley for fire control and wood-production purposes, since a great extent of excellent forest land is needlessly lying in waste. This may involve the problem of managing swamp lands for forest and game purposes, or

may, for example, provide for the enlargement of the present Minnesota National Forest. Such lands, important as their proper use may be from the viewpoint of conserving economic resources, do not appear to have sufficient bearing upon flood control to warrant consideration in this study.[4]

BOTTOM-LAND HARDWOODS

With the exception of the area of sandy plains and innumerable lakes of the "lumber woods" region of the Lake States, no other considerable body of forest land in the Mississippi Valley presents

[4] Data made available in the report of Nov. 28, 1927, issued by the Mississippi River Commission since the foregoing paragraph was written, seem to indicate that the presence and character of forests even in this region have a much greater influence on run-off than is usually supposed. The report states that below Pokegama Lake, near the headwaters of the Mississippi River, and just above Grand Rapids, Minn., a reservoir dam was built across the Mississippi River more than 40 years ago (1884). The run-off from the entire watershed above that point is collected in this and two other reservoirs in the same basin. Aside from evaporation, and allowing for change in the amount of stored water, the entire run-off of this watershed has passed through Pokegama Dam. Its discharge has been measured accurately for 42 years and checked from the discharges of the two reservoirs above; the rainfall has been measured daily at the three dams for the same period, and the area of the watershed has been carefully determined as 3,265 square miles. Of this area, 584 square miles are lake surface and 2,681 square miles are land surface.

The report of the Mississippi River Commission (p. 74) says: "The region is one where normal rainfall and normal evaporation are about equal. Therefore the rainfall over the lake surface is lost by evaporation and the measured run-off is that of the 2,681 square miles of land. Thus we have with great accuracy the three features necessary to a complete determination of the relation of run-off to rainfall—area of watershed, rainfall, and run-off. In the 42 years mentioned the basin has passed through all phases, from virgin forest, through the logging period, and forward to agriculture or backward to a growth of scrub and young timber—autoforestation. Because of the fact that much of this area is Indian reservation, and most of it poor agricultural land, it has largely gone backward rather than forward."

The report of the Mississippi River Commission furnishes the gist of the 42 years' observations, divided into six seven-year periods, in the form of a table, which is given below, supplemented by a final column furnished by the author of this circular showing the number of inches of rainfall retained by the watershed and the number of inches of run-off.

Seven-year periods	Average annual rainfall		Run-off	Run-off in percentage of rainfall	Water	
					Run-off	Retained
	Inches	*Millions of cubic feet*	*Millions of cubic feet*		*Inches*	*Inches*
1885 to 1891	25.318	1,103,856	222,745	20.18	5.108	20.21
1892 to 1898	26.417	1,151,774	261,460	22.70	5.997	20.42
1899 to 1905	29.687	1,294,967	442,545	34.17	10.147	19.54
1906 to 1912	24.446	1,066,379	252,565	23.68	5.786	18.66
1913 to 1919	25.420	1,108,292	284,002	25.63	6.510	18.90
1920 to 1926	21.583	941,078	148,933	15.83	3.413	18.17

The first three periods cover the time from virgin forest to practically complete deforestation, as far as pine timber, the principal native growth, is concerned, and the last three periods cover a gradual relapse to scrub with the growth of young timber (autoforestation), and some advancement to farms. It will be seen from the above figures that the percentage of run-off increased as deforestation advanced and decreased again as a growth of scrub and young timber gained foothold. More marked, however, is the influence of the forest shown by the figures in the last column, which indicate the number of inches of rainfall actually retained by the land. The average for the first two seven-year periods, which included the virgin-timber epoch, is 1.775 inches a year greater than the average for the last two seven-year periods. An absolute reduction in run-off of this amount applied to a large area would obviously have tremendous influence upon the action of the streams affected. In this particular case, however, the increase in run-off during the period of deforestation and the reduction in run-off as the forest is restored may be accounted for by a marked increase in average precipitation during the first epoch and a marked decrease during the last. The Mississippi River Commission, misunderstanding the theory of the application of the forest to the regulation of stream flow, compared these data with similar data from another watershed which was farmed extensively, and reached the conclusion "that farm lands reduce run-off more than do cut-over lands," a conclusion which is absolutely sound but is of little more than academic interest, since lands valuable for farming are not usually considered for forest purposes. The further conclusion of the commission "that cut-over lands have no greater run-off than do virgin forests" is a misinterpretation of the forest-protective influence shown by the above table, since the proper measure of effectiveness in a given condition is the number of inches of water actually retained by the watershed rather than the percentage of run-off.

so simple a problem from a flood-control standpoint as the timbered bottom lands of the Mississippi Delta.

This type of forest, from Cape Girardeau to the Gulf, can be said generally to be the forest type originally common to the lands now subject to overflow or in danger of inundation by floods. Such forests are of service in binding the soil along the stream banks and in checking destructive washing. They can not be said to increase or lessen flood volume materially, although they consume a great amount of moisture in the process of growth and thereby produce valuable material on lands which in an undrained condition were otherwise unproductive. Forests may even be undesirable when they occupy portions of the flood plain where the distance between the levees is narrow and rapidity of current is desirable, since they tend to retard stream flow. On the other hand, bottom land forests may be the best crop to raise on overflow lands where there is room for the stream to spread out. Since the forests tend to retard the flow, this aids the water to deposit its excess load of silt, thereby reducing its power to do damage as it travels on down the river.

The Delta hardwoods grow with unusual rapidity owing to the rich soil, heavy rainfall, and long growing season. Where the soils are properly drained and are assured protection from overflow such lands are of course too valuable to devote to forests. However, where the lands are poorly drained or where overflow is periodic, and particularly where the soil may be endangered either by being washed away or buried in a covering of river sand, trees may prove to be the most valuable crop. If, therefore, it should be found necessary for the public to acquire bottom lands for overflow or reservoir purposes, consideration should be given to their utilization as public forests, whereby their earning powers for wood production would be used as a means of lightening the burden placed upon the public by flood-prevention expenditures.

Above the Delta the bottom-land hardwood type continues to a considerable distance. However, in its northern extension it is chiefly stream marginal in character and falls in the general classification of farm woodlands. The necessity of exercising care in the management of such lands will be discussed in dealing with forest lands of that class.

UPLAND HARDWOODS OF OHIO RIVER BASIN

The entire Ohio River drainage, with the exception of about 17,000 square miles of prairie lands in Indiana and Illinois, was originally practically one vast forest, largely of hardwoods. There were limited amounts of northern white pine and hemlock in the upper Allegheny region in Pennsylvania and New York, and minor tracts in Ohio. Only a few remnants of these conifers are left. There were also limited forests of spruce and hemlock in the mountainous parts of West Virginia, North Carolina, and Tennessee, some of which continue unchanged as to type, although largely cut over.

In no other drainage basin of the Mississippi has human occupancy changed forest conditions to so great an extent as in the Ohio Basin. Of a total area of 203,782 square miles, of which 186,000 square miles was timbered, only about 68,000 square miles of forest or forest land remains. This is broadly described as falling into two classes: (1)

Comparatively contiguous bodies of timber in the mountainous and plateau regions; (2) farm wood lots, which are isolated small bodies of timber scattered through the better agricultural sections, and fringes of hardwood species generally found on the bluffs and banks of stream courses bordering agricultural lands.

The plateau and mountain forests are the only areas in the Ohio Basin requiring special discussion, since the farm wood lot and stream marginal woods in the regions essentially agricultural will be considered as a general class for all major basins of the Mississippi.

Proper care of forest land is particularly desirable in this basin, because it has a very high run-off for its area as compared with the other major basins. There is a striking contrast between its estimated average run-off of 300,000 second feet from 203,782 square

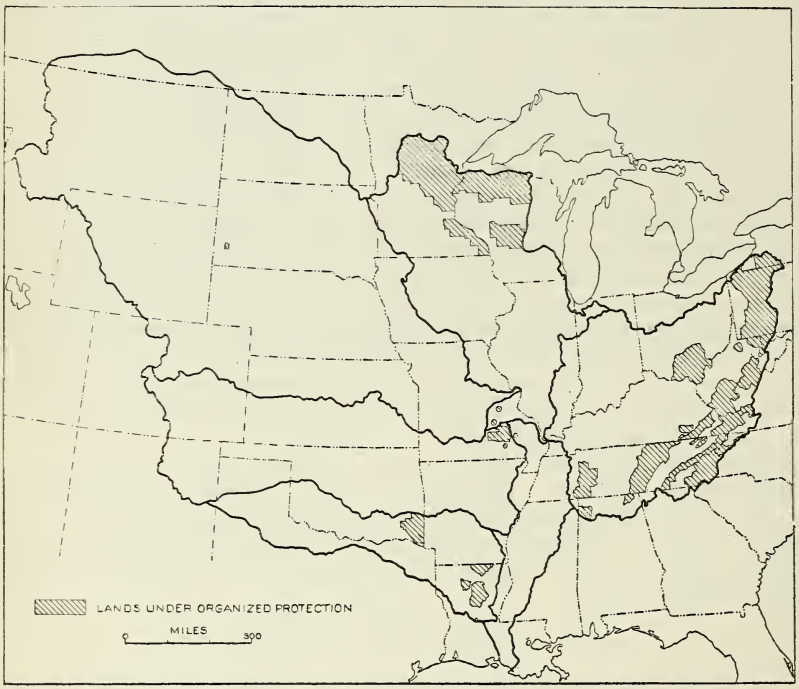

FIG. 7.—Area protected against forest fire (under Clarke-McNary law)

miles and the 100,000 second feet from 511,636 square miles in the Missouri River Basin.

By a glance at Figure 5, showing the distribution and density of forest lands in the Mississippi Valley, one sees that these plateau and mountain forests are two almost continuous bodies of land, largely in forest, practically paralleling one another but separated by the valley of the Tennessee River. The one lying to the south covers the most rugged parts of the southern portion of the Appalachian Mountains. The more extensive one to the north and east is known as the Cumberland Plateau through Kentucky and Tennessee and as the Allegheny Plateau in West Virginia and Pennsylvania. A remnant of this formation having a high percentage of forest land lies in

western Tennessee just east of the river of that name and quite removed from the main portion of the plateau.

In the more southerly Appalachian Mountain region the plans of the Federal Government for forest protection and stream-flow regulation have already been well crystallized, as will be seen from Figure 8. Practically all of the region, containing more than 75 per cent of forest land, is already within the boundaries of national forests created from purchased areas established by the National Forest Reservation Commission under authority of the Weeks law, or in the Smoky Mountain National Park more recently authorized by Congress. The task of completing the actual purchase of the forest lands within these units remains. The same statement holds true for the several national forests on the Allegheny Plateau farther north, and for that part of the Alabama National Forest lying within the Ohio Basin.

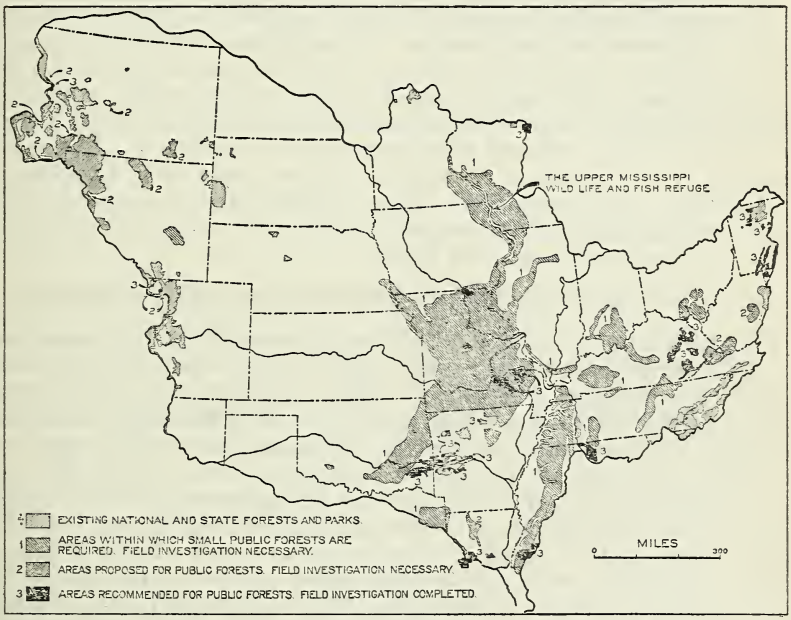
THE UPPER MISSISSIPPI WILD LIFE AND FISH REFUGE
½ EXISTING NATIONAL AND STATE FORESTS AND PARKS.
1 AREAS WITHIN WHICH SMALL PUBLIC FORESTS ARE REQUIRED. FIELD INVESTIGATION NECESSARY.
2 AREAS PROPOSED FOR PUBLIC FORESTS. FIELD INVESTIGATION NECESSARY.
3 AREAS RECOMMENDED FOR PUBLIC FORESTS. FIELD INVESTIGATION COMPLETED.
MILES
0
300

FIG. 8.—Reservations: Existing and proposed

There is still, however, a wide gap between plans and accomplishment as far as actual purchases of land in the national forests in the Ohio Basin are concerned. The total area within such forests is 3,931,476 acres, while the area of net Government land acquired is only about 700,000 acres. However, lands are steadily being offered for sale, and purchases are being made by the Government. These national forests will doubtless ultimately be carried to completion without receiving any further consideration from a flood-control standpoint.

The conditions which necessitated the establishment of public-protection forests in the main mountain range are found to exist in equal degree over a considerable extent of the plateau lying north of the Tennessee River and terminating in the Allegheny National

Forest in Pennsylvania. Within this region a number of areas have been examined by the Forest Service under the provisions of the Weeks law and found to meet the requirements of public-protection forests. These areas are shown in Figure 8, and are indicated by the numeral 3. The examiners' reports have shown that such areas are sadly in need of protection, but the funds at the disposal of the National Forest Reservation Commission have never seemed sufficient to justify a recommendation that the commission extend its program to this region. Another deterrent feature has been the fact that much of the area is underlain with coal, which necessitates limiting purchases to surface rights, with a mineral reservation and use running to the mining company. However, in other mineral regions it has been found practicable to meet this situation through a division of surface and subsurface rights, and there is every reason to feel confident this plan will prove workable here.

Three other units, shown in Figure 8 and indicated by the numeral 2, are roughly outlined areas which are reported as urgently in need of public protection-forest status. In addition, a considerable number of regions are outlined in Figure 8 and indicated by the numeral 1, within which there are areas of greater or less extent which are eroding badly and from which unnecessarily turbid and flashy run-off contributes to the general flood problem of the basin. The establishment of such areas as protection forests would be a contribution to regularity of stream flow. These regions are recommended for future consideration and examination with a view to determining the proper ultimate status of such lands.

SOUTHERN-PINE REGIONS AND ADJOINING UPLAND HARDWOODS

The Southern pine and adjoining upland types of forests are treated together as a single region, for the reason that they are found closely intermingled and allied. Their territory includes all land outside of the bottom-land hardwood type in Mississippi, Louisiana, Arkansas, the southeastern third of Oklahoma, the northeastern corner of Texas, most of the State of Missouri south of the Missouri River, and that part of Tennessee and Kentucky not drained by the Ohio. Pine predominates in the Mississippi region south of the Black River in Louisiana, and in Arkansas south of the Arkansas River. Elsewhere west of the Mississippi the two types divide the territory about evenly. East of the Mississippi and north of Black River upland hardwoods prevail, these being in reality a continuation of the vast hardwood belt extending westward from the Ohio Basin.

While forest depletion is far advanced in this region there still remains a much larger acreage of virgin timber than in any other forested region of the United States east of the Rocky Mountains. Cutting for commercial lumbering and clearing for agriculture have advanced farther as a whole in the pine type than in hardwoods. Considered separately, commercial lumbering has made greatest inroads in the pine forests and clearing for agriculture has made greatest advances in the hardwood type. This is the natural result of pine being most in demand for milling purposes and of the hardwood lands having generally richer soils than the pine lands.

Because of even topography and sandy soils, a considerable part of the pine land west of the Mississippi, like the sandy pine land of the Lake States, does not erode readily and quickly absorbs rainfall to

the limit of the capacity of its soils. For this reason the presence of forest cover is not essential from the standpoint of stream-flow regulation. Consequently large parts of the forest lands as shown in Figure 5, although largely in an unsatisfactory state from the standpoint of timber production, are not shown as critical areas upon which the maintenance of good forest cover is essential to stream-flow regulation. This statement holds good for a considerable part of the pine lands of Louisiana and Arkansas. However, several areas of comparatively rough or broken lands, with prevailing steep slopes are shown in Figure 6, which are exceptions to this rule. Upon these the maintenance of the forest is necessary to prevent erosion and freshet run-off. The same condition prevails on the areas of pine lands indicated as critical in Figure 6, in Arkansas, Oklahoma, and Missouri. The establishment of the Ouachita and Ozark National Forests in Arkansas has resulted in improved conditions in that portion of the State which embraces the rougher regions. However, the problem of fire protection has proved so difficult that even now these areas can not be rated better than neutral from a watershed standpoint. If protection from fire can be made effective, these should eventually become beneficial. However, much still remains to be done before satisfactory fire control is realized. Public sentiment appears to be changing in favor of fire prevention, as against the long-standing practice of woods burning.

Lying east of the Mississippi and extending from southwestern Kentucky on the north through Tennessee, Mississippi, and Louisiana on the south, is a long, comparatively narrow area which as a flood menace and erosion problem appears to be by long odds the most serious and important of any in the Mississippi Valley. The white area adjoining it on the west, as shown in Figure 6, is bottom lands. The area shown as critical is high land. This is a region of exceedingly deep and loose soils, subject to excessive erosion. These soils are of wind-blown origin, picked up from the river-borne silt through the endless ages, and deposited by the prevailing winds from the west. The soils are deepest and conditions most critical, generally speaking, along the western rim and shade off gradually toward the east. Examples of vertical gully erosion 20, 40, and 60 feet deep, are not uncommon. One case was reported with a depth of 160 feet. This condition of deep, loose soils in a region of heavy rainfall requires a very slight slope to start destructive erosion. In one drainage unit—the Homochitto—the 1925 census shows a reduction of about 30 per cent in plowlands as compared with 1920, due largely to the enforced abandonment of eroded fields. Within this unit the secretary of the National Forest Reservation Commission has examined the two areas outlined, one of 218,000 acres and another of 420,000 acres, as shown in Figure 8, with a view to recommending purchase by the National Forest Reservation Commission. However, a portion of the eastern area is not essential to stream-flow regulation. The total of the two areas so classified is found to be 546,000 acres. The Mississippi enabling act at present limits forest-land purchases by the Federal Government to only 25,000 acres, and this should be given consideration in planning an immediate program of Federal purchases.

The urgent necessity of exercising care in handling the lands in this region of delicate balance can not be overestimated. It is im-

portant from a flood standpoint; it is important from a drainage standpoint, since the silt from these lands fills the drainage canals on the lowlands; not only is it important for the protection of the lowlands from silt and floods, but the protection of these lands is also vital to the future usefulness of the region itself. Destruction is now taking place that can never be remedied. Much of this destruction can be stopped, but it will require real effort to stop it. The entire area is, therefore, shown in Figure 6 as "detrimental" and recommended for examination with a view to determining what portions are so subject to erosion that they should be permanently kept in public forests for protection purposes. These will be the steeper, rougher lands along the western border of this general soil type.

PROTECTION FORESTS IN COMMERCIAL-TIMBER REGIONS

The largest areas in urgent need of protection forests are found in the commercial forest regions of the Appalachian, Ozark, and Ouachita Mountains, the Cumberland Plateau, a few broken areas in the southern pine regions and adjoining hardwoods, and an area at the head of the Wisconsin River. These have been referred to in the discussion of the different regions and are indicated in Figure 6.

The importance, from a national standpoint, of prompt action and the great acreage that must still be left to local initiative requires that immediate steps be taken by the Federal Goverment toward the acquisition of more protection forests in the Mississippi Basin. With the concurrence of the State authorities, and in consultation with them to avoid conflict with any State forestry programs, the Government of the United States should approve as purchase units all areas within the commercial forest regions meeting the standard requirements governing the National Forest Reservation Commission in the execution of the Weeks law. This, of course, limits immediate action to the scope and regions approved by the legislatures of the several States. With these points in view a number of areas considered in this study have been listed in a tentative program for the purchase of protection forests needed on the Mississippi watershed. Such purchases, if authorized, should be made by the Forest Service of the Department of Agriculture under the approval of the National Forest Reservation Commission.

TABLE 5.—*Purchase areas* [1]

Area	Acres	Area	Acres
Additions to the Ouachita National Forest in Arkansas	313, 240	Kentucky-Cumberland area in Kentucky	900, 000
Additions to Ozark National Forest in Arkansas	120, 000	Kentucky area in Kentucky	478, 000
Additional forest in Oklahoma	855, 355	Pearson Hills area in Alabama	478, 000
De Soto area in Louisiana	230, 000	Levissa Fork area in West Virginia and Kentucky	800, 000
Jackson area in Louisiana	500, 000	Tug Fork area in West Virginia	430, 000
Little River area in Louisiana	85, 600	Elk and Gauley area in West Virginia	629, 000
Licking area in Kentucky	323, 000	Homochitto area in Mississippi	25, 000
Pine Mountain area in Kentucky	450, 000	Wisconsin River area in Wisconsin	100, 000
Quicksand area in Kentucky	268, 000		
			6, 985, 195

[1] For location of proposed reservations, see fig. 8.

Probably not more than 85 per cent of the total acreage of these areas would be purchasable by the Government for protection forests. No land more valuable for farming than for forestry should be acquired. In mineral regions titles should be limited to surface rights, the present owners retaining their property interest in the minerals with the right to remove them under terms equitable both to the owner and to the public. In round numbers the total of purchasable land within the areas listed is estimated at 5,900,000 acres. The cost at an estimated average of $5 per acre totals $29,500,000, or an average of $2,950,000 a year if spread over a period of 10 years.

This does not include the additional areas from which lands are being currently approved for purchase by the National Forest Reservation Commission within national forests already created under the Weeks law. The purchasable lands not yet acquired within such limits on the Mississippi watershed are estimated at about 2,642.000 acres. This added to the 5,900,000 acres additional herewith recommended would make the total of forest-land purchases on the watershed proposed as a Federal activity, 8,542,000 acres, with a total expenditure of $42,721,000, or $4,272,100 annually if spread over a period of 10 years. Including the national forests already created from the public domain or acquired under the Weeks law, the total area of protection forests owned by the Federal Government in the Mississippi Basin would thus ultimately become 25,822,000 acres. This is slightly over 16 per cent of the forest lands on the drainage, or about 3 per cent of the total area of the drainage.

Even with the Federal Government assuming this part of the burden, there are still large areas where public forests, State, county, or municipal, would appear to be the only satisfactory solution. The field for local initiative will still be large enough to tax to the utmost the possibilities of State, county, and municipal forest ownership and leave a large field for private ownership. This is particularly true of that part of the Cumberland Plateau lying within the State of Tennessee, where the State legislature has not given its consent to purchases by the Federal Government more than 20 miles west of the North Carolina boundary. The problem will also be a difficult one in the State of Mississippi. Changes in the present enabling legislation of the States, with respect to Federal purchases under the Weeks law, may require some modifications in the purchase areas listed above for Federal action.

FARM WOODLANDS

The most difficult part of the forest problem on the Mississippi drainage is that having to do with the 115,000 square miles of forest land in farms and in regions primarily agricultural. This naturally arises from diversity of area, location, character, and ownership. The problem is exceedingly complex. The land is within the absolute control of millions of individual independent farm owners who are usually unaware that other interests may be injured if the hillside forests are overgrazed, burned, or cleared off.

Though the lumberman may be fairly charged with a large share of responsibility for unwise forest destruction, it is only fair to state

the fortunate circumstance that after he has destroyed the virgin forests by utilization—wise or otherwise as the case may be—he usually moves on and leaves the field to nature and her curative processes, also, unfortunately, to the merciless inroads of repeated fires. With the farmer the situation is different. His settlement is permanent in design. His stability is nearly always a splendid virtue, invariably so if the land which he clears and cultivates is suitable for permanent farming. Where he makes a mistake and clears land that quickly loses its fertility under the wash of rainfall, he is reluctant to give up the fight. So much of his labor has gone into the land itself and must be abandoned if he goes elsewhere that he refuses to surrender, and only does so when driven to the utmost extremities of poverty. The process of trial and error in the use of land for farming was started in the Mississippi Valley by the first settlers who crossed the mountains at the headwaters of the eastern tributaries of the Ohio River about Revolutionary days and has been going on ever since.

As a people we are still somewhat young and inexperienced. Like the young man who fancies his inheritance is inexhaustible, we fancy that soil fertility is a fixed condition inherent to land in the very nature of things, and we clear land on steep slopes and use it for intertilled crops where similar land in older countries would either be kept in forest or would be terraced before being plowed. The fact of excessive soil erosion from farms is so conspicuous in every report on a drainage unit including considerable quantities of farm lands that it becomes the outstanding finding of this study.

This excessive erosion is taking place from three classes of lands: (1) Lands originally prairie which are too steep in slope for cultivation and should be kept in sod and used for pasture or hay lands; (2) lands along the margins of streams or in narrow draws where trees are the only growth strong enough to withstand soil washing and bank cutting; (3) most important of all, land originally timbered on slopes too steep for tillage without terracing. In some places the proportion of such land under plow is considerable. The report on one drainage unit where soil erosion is particularly malignant shows that 30 per cent of the total area under plow was abandoned between 1920 and 1925, largely because of soil losses. The serious damage appears usually to be limited to a few acres in a place—a steep slope here, a gully there, an unprotected stream bank, or the like. However, in the aggregate much greater damage is in many regions taking place in the insidious form of sheet erosion, often without the owner of the land realizing that injury is being done to his own property, to say nothing of the fact that a national problem is being made more difficult. The damage by gully washing is more obvious.

From any one piece of land in the Mississippi Valley the contribution of eroded soil is usually small, but the aggregate would make an impressive total. Furthermore, from certain highly vulnerable soils the contribution of silt tonnage is often enormous. In addition, the adverse effect on water storage and water flow of the neglect of a small area may be far-reaching. A single gully of less than a quarter of an acre may add more to the destructive power of a flood than the clear run-off of an entire section of well-managed fields

or woods. The misuse of farm soils is not a sin peculiar to one class or region. It is far too common north, south, east, and west.

This fact of the mismanagement of farm soils runs through all the unit reports. Through all the reports there also runs evidence of mismanagement of farm wood lots owing to lack of technical knowledge or advice. The most prevailing fault is overgrazing, often to the extent of killing out all undergrowth and young reproduction within the reach of stock, exposing the tree roots as a result of soil washing and tramping, and preparing the way for the loss of protective litter from winds sweeping through the open parklike growth. All this greatly reduces the value of the area either as a timber-producing property or a soil and moisture conserving property. In most cases also the pasturage is of low value. In consequence of the overgrazing of farm wood lots and the erosion of farm lands being so general and so widespread, it appears best to cover the farm wood-lot and farm-soil erosion problem for the Mississippi Valley as a whole rather than for each major basin separately.

How to secure better management of farm wood lots is largely a question of education and extension. It involves awakening to action, based upon better understanding, the owners of the 115,000 square miles of wood lots and waste land lying within farms. The importance of this problem from a national standpoint was recognized by the Senate Select Committee on Forestry in its report which resulted in the enactment of the Clarke-McNary law, June 7, 1924. Sections 4 and 5 of this law provide for cooperation through the States with the owners of farm wood lots.

It is understood that the Senate committee's endorsement of wood-lot appropriations was based primarily on the national economic importance of the wood lots from a wood-supply and agricultural-betterment standpoint. If this work is at all worth its cost by reason of such returns, then by all means it may well be speeded up on account of its contribution to the regulation of stream flow. At first thought the use of farm woodlands may appear to be a minor factor in flood control, but such is not the case. We are dealing with very great acreages. If by the stimulation of better management of farm wood lots we can bring about an average increase of 2 inches in the layer of humus, that means an increase in water-storage capacity of 1,815 cubic feet for each acre so transformed. On a total of 115,00 square miles the increase in water-storage capacity would amount to 133,854,000,000 cubic feet, or the equivalent of the entire average run-off of the Mississippi River system above Quincy, Ill., averaging 72,899 second feet, for a period of over 21 days, or a flow of 1,000,000 second feet for over 37 hours. The resulting effect of mechanically retarding run-off would be very much greater.

We have also to consider the possibilities of forest planting on eroding farm lands as a check to erosion. Experiments conducted by the Missouri Agricultural Experiment Station showed that six plots having a gradient of only 3.71 to the hundred handled under different conditions—not cultivated, plowed 4 inches, plowed 8 inches, planted in wheat annually, planted in corn annually, rotating corn, wheat, and clover—lost soil at an average rate of 23 tons per acre a year over a six-year period, as compared with an average annual

loss of about 562 pounds on a seventh plot under sod. The farm lands in the Mississippi Valley which should be planted to forests are waste lands and lands which can not be cultivated or retained in sod as pasture or meadow land without excessive erosion. Such lands are usually much steeper than those employed in the Missouri experiment. Gradients in excess of 5 per cent and up to 15 per cent or even 20 per cent are not uncommon. Under such conditions even heavier erosion might properly be expected. Successful forest planting would in 5 to 10 years reduce the average annual loss by erosion to a negligible factor. The present appropriation of $75,000 a year for aiding timber planting on farms, under the Clarke-McNary Act, can be credited with stimulating the planting on farms of 30,000 acres during 1926, which would not have been reforested without this contribution. If half of this expenditure and half the acreage is in the Mississippi Valley on sloping land similar to that in the Missouri soil-erosion experiment, this would mean eventually the withholding of about 345,000 tons of silt burden from our streams each year as a result of this 1926 expenditure, or slightly more than 9 tons of silt for each dollar originally expended. This would make the cost to the Federal Government of a single year's service less than 11 cents a ton. Spread over a period of 11 years, it would be 1 cent per ton.

But it should not be forgotten that the appropriation for planting farm wood lots was not made primarily for flood-control purposes. It was made for farm-land betterment and to help safeguard the Nation's future timber supply. Therefore, in estimating the importance of this work it must be given credit for the soil fertility which is saved from being irrecoverably lost and for the value of the wood crops, as well as for the increase in the moisture-holding capacity of the land by leaf-litter accumulation, for the greater permeability of the soil, and for the prevention of siltage in streams.

From the standpoint of the public benefits realized for each dollar of Federal money expended on flood-prevention forests, the greatest returns may be expected from that part of the Federal funds authorized to be appropriated under section 4 of the Clarke-McNary law which is used in the stimulation of planting on eroding or other waste lands in private ownership. The owner furnishes the land, plants the trees, and continues to look after them entirely at his own expense, while the most the Federal Government and State do is to help furnish the planting stock and give advice. The landowner, of course, owns the timber when it grows up, but his timber protects the watershed of the great river just as effectively as though the public had paid the entire bill.

Along with this activity must go cooperation under section 5 of the Clarke-McNary law, which authorizes the Secretary of Agriculture to cooperate with the States in assisting "the owners of farms in establishing, improving and renewing wood lots, shelter belts, windbreaks, and other valuable forest growth and in growing and renewing useful timber crops." The close relationship between these two sections is shown by the fact that 23 States in the Mississippi drainage are now cooperating with the Federal Government under section 4 and 21 under section 5. Under section 4 the farmer is aided in securing suitable forest-planting stock at a cost which makes planting a practical business venture. Under section 5 he is given expert

advice in caring for his wood lots and other forest growth. Planting stock and tree seeds must be provided to restore forests on the 10,000 square miles of idle or waste lands in farm ownership in the Mississippi Basin. The farmers also need advice in managing the 105,000 square miles of farm woodlands which do not require planting but whose improvement will add greatly to the protective forest cover on the drainage.

It is desirable that additional funds be provided for Federal encouragement of forest planting on lands in private ownership in the Mississippi watershed as rapidly as the States are organized to extend this work and the owners can be induced to plant up their waste and idle land or eroding slopes. The increase in funds for giving advice on the care of farm wood lots should keep pace with the needs for such service.

This is undoubtedly the most practical method of solving the forest-watershed problem on lands best suited for forest purposes in farm wood lots and regions predominantly agricultural. The expenditures by the cooperating States in this work are already more than double that of the Federal Government, although the section 4 expenditures are usually returned to them in the form of receipts from sales of planting stock. The private cooperator is enabled through the operation of this law to secure his planting stock at actual cost of production. Without such a provision the costs of planting farm wood lots are usually prohibitive.

By this arrangement the expense to the private owner of forest planting in small areas is greatly reduced and progress in this improvement of stream-flow conditions correspondingly accelerated. It is estimated that there is a total of 22,400,000 acres of waste land in the Mississippi Basin requiring reforestation, of which 6,400,000 acres is in farm ownership. While much of this land is not eroding, none of it is in a satisfactory condition from a water-storage viewpoint. In the long run it is certain that the reforestation of this land would be a splendid economic investment from a national standpoint, particularly under a policy whereby the private owner bears four-fifths of the costs. On the basis of 1926 figures the present arrangement works out as equivalent to a Federal subsidy of about $2.50 per acre for every acre planted. However, owing to the necessity of purchasing land and starting new nurseries, the present unit costs are high. With a larger acreage and well-established nurseries, equivalent service can be furnished in the future at lower cost.

All the waste or wasting land in the basin should be reforested within 20 or 25 years. It will not be done unless strong public assistance and backing are given. Under the existing conditions the Nation appears to face a $56,000,000 task if the Government must contribute $2.50 per acre for every acre needing reforestation. It is believed, however, that with experience in planting and in managing and marketing forest products and with the realization of the resulting benefits, the private owners will take sufficient interest in putting their lands in condition to grow steadily in value without further effort except protection from fire, so that further planting subsidy will be unnecessary. The final cost to the Federal Government of securing the restoration of the 22,400,000 acres of waste lands to forests should not exceed a total of $5,000,000, or less than 25 cents

per acre. Doubtless technical advice under section 5 of the Clarke-McNary law will always be necessary, since there is always a new generation of landowners growing up and since better methods of forest management will doubtless be worked out as time goes on.

PLOWLAND ALSO NEEDS ATTENTION

Extension activities in forest planting and forest management should be coordinated with extension activities in promoting better practices in farming slope lands, such as contour plowing, crop rotation, keeping steep lands in sod for hay or pasturage, and terracing according to the degree of slope and danger of washing. Wiser selection of lands for cultivation should be urged so that on lands agriculturally submarginal, and hence more productive for forest than farm crops, agriculture should not be attempted. County agents everywhere should advise against clearing slopes for cultivation unless the owner of the land is prepared to take whatever action may be required to prevent erosion and preserve the fertility of the soil. Owners should be encouraged to check further damage to their fields not only in order to prevent soil depletion but to secure the advantage of heavier crop production which follows effective terracing and the more productive use of rainfall.

There should be no conflict between the campaign for better farm practice and that for better forest practice on farm lands. The general aim should be to protect soil fertility from being destroyed by either unwise use or neglect. Unless the farmer is prepared to prevent the rich topsoil from washing away on sloping land, he should keep it in trees. However, the forest may properly be displaced whenever the productive value of the land for other purposes makes it more profitable to so use it, taking into account the expense of terracing or other soil conservation costs, if such protective work actually follows clearing.

There will always be some erosion from farm lands and some loss of soil fertility which is avoidable only at unreasonable cost. The practical application of the remedies herein proposed would not be a burden on agriculture. On the other hand, heavier crops under terracing and contour plowing and through prevention of land destruction and soil impoverishment by reforestation or sodding of slopes will offset the original cost of the necessary protective measures many times over. It is estimated that within 20 years it should be possible by an aggressive campaign of education and extension to bring about a general application of the principles stated in the two preceding paragraphs, which in turn should reduce the total silt burden now coming from cultivated fields in the Mississippi Valley to not more than 25 per cent of its present volume. Present practices would have to be changed on a very great acreage of farm lands in the aggregate although on a relatively small part of the total area under cultivation. Such an extension campaign seems to be justified by its direct economic advantages. At the same time, without additional costs it would make a very material contribution to flood prevention by reducing the burden of silt and by increasing the absorptive and storage capacity of lands now most subject to rapid run-off.

No recommendations are made as to legislation, organization, or appropriations for such a campaign of extension, since it does not come within the jurisdiction of the Forest Service. It has, however, appeared necessary to consider this feature of the flood and forest problem at some length in order to determine fairly the relative importance of forestry in conserving soils and moisture on farm lands. Such a campaign of rural education falls within the field of jurisdiction of the extension service of the Department of Agriculture.

THE PLACE OF PROTECTION FORESTS IN REGIONS PREDOMINANTLY AGRICULTURAL

However, the fact must be reckoned with that there are some agricultural regions in which the problem can not be solved by the resident owners with assistance of the kind mentioned above. In some regions the broken topography and large extent of forest lands on slopes which are subject to erosion present a difficult problem, too difficult for satisfactory solution under diversified private ownership. In such places the only final answer seems to be public ownership and management in blocks of several thousand acres. Examples of this kind are not uncommon in the unglaciated region east of the Mississippi River from the mouth of the St. Croix River south to the vicinity of Beloit, Wis. Again, in the southern part of Illinois forest lands form a continuous belt stretching for many miles along the bluffs. Timbered bluffs are also not uncommon in southern Minnesota and in Iowa and Missouri. In the latter State, in regions largely devoted to agriculture, large blocks of true forest lands, rough and unsuited for cultivation, are not uncommon, particularly in the southern half of the State. Indiana, Ohio, Kentucky, and Tennessee also furnish many examples of similar conditions outside the rougher mountainous region.

In all the States named, from Wisconsin to Tennessee, practically continuous areas of forest lands in rough country, in tracts ranging from 5,000 to 50,000 acres in extent, are not unusual. Such forest lands are not within the territory which the National Forest Reservation Commission has under existing policies considered for Federal purchases. However, these rough timbered regions appear admirably suited for public forests, probably under county, city, or State ownership, and the individual States appear well able financially to assume this burden with ultimate public profit. Such enterprises, well and profitably managed locally, should go far toward stimulating local pride and self-reliance. This, in turn, would increase local initiative, self-confidence, and self-help—which it is in every way desirable to stimulate in preference to dependence upon Federal aid and leadership.

In addition, there are considerable areas of bottom lands now in forests which these States might well purchase and retain for timber production, recreation, and overflow purposes. At present high waters are allowed to spread out on such bottom lands, the current is slowed down, and the sediment settles and is kept out of the main channels. Under private ownership there is always danger of such land being dyked or leveed, thereby accentuating both the local and general flood problem. The Federal Government is making a good start in purchasing bottom lands for wild-life refuge purposes along

the middle reaches of the Mississippi River as indicated in Figure 8. The purchase of critical areas of overflow lands on the tributary streams should not place an unreasonable burden on each State directly concerned.

NATIONAL FORESTS, NATIONAL PARKS, PUBLIC DOMAIN, AND GAME-REFUGE FORESTS

In the interest of simplicity it is desirable to deal with the national forests, national parks, and public-domain and game-refuge timbered lands as a separate problem from non-Federal forests. Table 6 shows by square miles the gross area of national forests within the Mississippi drainage basin by States and major basins.

TABLE 6.—*Gross areas of national forest lands, by basins*

State	Ohio	Upper Mississippi	Missouri	Arkansas—White	Red—Ouachita	Total
	Square miles	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*
Alabama	57.3					57.3
Arkansas				1,651.6	798.0	2,449.6
Colorado			4,487.7	2,080.4		6,568.1
Georgia	498.6					498.6
Illinois		16.7				16.7
Kentucky	35.3					35.3
Minnesota		464.2				464.2
Montana			14,013.6			14,013.6
Nebraska			323.6			323.6
New Mexico				107.0		107.0
North Carolina	1,890.3					1,890.3
Oklahoma					96.3	96.3
Pennsylvania	1,155.1					1,155.1
South Dakota			1,986.6			1,986.6
Tennessee	1,343.8					1,343.8
Virginia	333.9					333.9
West Virginia	828.6					828.6
Wyoming			7,445.5			7,445.5
Total	6,142.9	480.9	28,257.0	3,839.0	894.3	39,614.1

On the Mississippi drainage there are also three large national parks having important bodies of timber—the Glacier, having an area of 160 square miles in Montana; the Rocky Mountain, 208 square miles in Colorado; and the Yellowstone, 2,864 square miles in Wyoming and Montana.

For the total area in the national forests and parks the general statement can be made that the continuance of existing policies will meet watershed-protection requirements in a satisfactory degree. The lands in the national forests and national parks are being protected from fire and managed either for their forest or scenic values. A considerable part of these lands within the exterior boundaries of national forests and national parks, particularly in the Ohio Basin and in Arkansas, is still privately owned. However, they are all either within purchase units or in national forests where acquisition by exchange is authorized, and ultimately all lands not more valuable for agriculture or some other purpose than for forest or park purposes may be expected to pass into public ownership unless existing laws are repealed.

But such is not the case with the forest lands of the public domain. These lands are Federal properties for which Congress has established no policy further than to restrict their addition to national

forests by presidential order. There are a number of areas adjacent to existing national forests which have been examined by field agents of both the Departments of Agriculture and Interior and found suitable and valuable for national-forest purposes. Such areas have been recommended by both departments and by the National Forest Reservation Commission for inclusion in national forests, and the reports have been transmitted by the President to Congress for action. No action has been taken on these areas by that body. There are still other areas of forest lands in the public domain awaiting further consideration and study by the Forest Service, but for which the information now available is not sufficiently definite to permit the drafting of legislation in other than general terms.

Generally speaking, the remaining areas of forest lands in the public domain are not yet in bad shape from a water-control standpoint, although far from being in as satisfactory condition as the adjoining national forest lands which have been systematically protected from fire and overgrazing for the past 20 years or more. However, with increasing demands for various kinds of wood products, these unreserved forests are eventually certain to be misused. They should be put under Federal forest management by including them in adjoining national forests instead of waiting until the damage is done and then undertaking the generation-long task of rebuilding resources which were negligently and unnecessarily allowed to be destroyed. If Congress will give the President power to act direct, the Forest Service can within 90 days submit final recommendations covering all the public lands on the Mississippi watershed in Montana, Wyoming, Colorado, and New Mexico, which are suitable for inclusion in national forests. The total areas of unreserved Government forest lands on the watershed of the Mississippi River which should be added to existing national forests would probably not exceed 700 square miles.

Another Federal land activity having a direct bearing on the Mississippi flood problem is the purchase by the Bureau of the Biological Survey of the Department of Agriculture, under a special act of Congress, of the overflow lands directly tributary to the main channel of the river from Wabash, Wis., to Rock Island, Ill. This area, which is known as The Upper Mississippi River Wild Life and Game Refuge, is shown in Figure 8. Its gross area is 265,000 acres, of which 165,000 acres is land and 100,000 water.

The forests along the stream margins come within the classification of protection forests, since they are most effective in preventing the cutting of banks. Furthermore, public acquisition of these overflow lands safeguards their being held as tributary reservoir areas available during overflow periods. Under private ownership there was always the menace that at some future time they, too, would be dyked or leveed for farms, the channels narrowed accordingly, the upper flood waters correspondingly hastened, and the problem below Cairo intensified.

THE BAD LANDS AND THE BREAKS

Two outstanding examples of serious regional erosion of nonforest lands are so clearly connected with regions of general Federal ownership and are so important from a stream-flow standpoint that their

omission from this study would be shortsighted. These are the Bad Lands and the Breaks.

In the Missouri River Basin in North Dakota, South Dakota, Wyoming, and Montana are a number of areas, most of which are indicated in Figure 6, which are familiarly known as Bad Lands. A large part of these lands is in the public domain and is of no known value or of practically negligible economic value. The Bad Lands aggregate about 15,500 square miles and form a great single class of land having an enormous effect on erosion and run-off.

Space does not allow a detailed description of typical Bad Lands. It is sufficient for the purposes of this circular to say that they have a clay soil and very scanty cover. The character of the precipitation of the Bad Lands regions is similar to that of the region of the Missouri experiment. Unquestionably from these areas comes a considerable part of the silt which gives the Missouri the name of "Big Muddy." In this connection it is worth while to note that the Missouri River is clear at the junction of the Jefferson, Madison, and Gallatin at Three Forks, Mont. It is usually still comparatively clear at Great Falls and Fort Benton, once the head of navigation. Its mountain tributaries come from national forests or from two great national parks, the Yellowstone and the Glacier. They come from the regions of steepest slopes and heaviest precipitation of the northern part of the basin, but because of the protection given to these watersheds by the Federal Government's national forests and parks, the streams are clear and pure. As soon as the river begins to receive the run-off from areas of Bad Lands it immediately takes on a muddy character which it retains until it transmits its burden of water and silt to the Mississippi River.

No data are available showing quantitatively the amount of silt contributed to the Missouri by Bad Lands areas. However, very good data have been published by the Missouri Agricultural Experiment Station showing the amount of soil eroded from a bare slope having a gradient of 3.71 per 100. In a six-year period during which the average annual precipitation was 35.87 inches the average loss was 34.95 tons per acre annually. The average annual precipitation for the Bad Lands regions is about 15 inches. The average slope would undoubtedly be much greater than 3.71 in 100. If the Bad Lands erode as readily as the Missouri soils and in direct ratio to the total precipitation the contribution of these 15,504 square miles would be annually $15{,}500 \times 640 \times 34.95 \times (15$ divided by $35.87)$, or over 144,000,000 tons. An unpublished report of the War Department estimates the annual discharge of solid matter by the Missouri as 413,000,000 cubic yards, or, at 2,700 pounds per cubic yard, about 557,000,000 tons. It thus appears that approximately 26 per cent of the total sediment contributed by the Missouri River may come from 15,500 square miles of country, or less than 3 per cent of the watershed. If we take Dole and Stabler's figures (1909) of about 180,000,000 tons as the usual sediment carriage of the Missouri, the Bad Lands contribution is 79 per cent of the whole. This is no doubt too high a proportion.

These calculations are not presented as being of direct or immediate value in determining flood factors. They are, however, believed to be of value as indicating sources of trouble which should be

carefully investigated. They make clear the fact that the great influence of these areas, and the possibilities that some means may be found to reduce their destructive power by vegetative covering, justify making the Bad Lands a matter of special research. As properties they would attract private enterprise only as they might be made to produce remunerative crops. As a Federal responsibility they present other responsibilities, such as checking the burden they contribute to the silt problem of the Mississippi and possibilities of eventual reclamation for some useful purpose.

A serious erosion problem somewhat analogous to the Bad Lands of the northwest is presented by the Breaks of the southwest. This is the region which marks the boundary or break between the Staked Plains of the Texas panhandle and the lower rolling red prairie country to the east. The steepness of the escarpment between the lower edge of the Breaks and the High Plains seems to be due generally to a rock cap which underlies the plains and preserves their surface until undermined and broken off.

The rain falling on the High Plains is almost entirely soaked up by the soil. The run-off, and consequently the erosion, occurs in the Breaks themselves, which extend back along the valleys being cut by the upper tributaries in Texas and western Oklahoma.

Soil erosion is extremely active through the Breaks region because of a combination of many steep slopes, scanty vegetation, abundance of easily eroded soil, and sudden hard rains. It is from this region that the Arkansas and Red Rivers draw their first great burden of silt, and it is this source of silt which the population of those two great drainage basins must reckon with in their plans for development, including the storage of water in reservoirs for irrigation, power, municipal supply, or other purposes. Unless the burden of silt carried by the local streams can be greatly reduced, the storage capacity of reservoirs in that region will be diminished very rapidly.

Merely from a flood-prevention and erosion standpoint it is believed that the Bad Lands and the Breaks are of sufficient importance to justify special study and investigation. The method of stopping erosion is a problem for research. Several species of trees and shrubs, together with many hardy grasses, grow in the regions, but the task of establishing them where extreme drought conditions prevail for long periods of time, and on bare slopes which disintegrate rapidly and wash away, promises to be extremely difficult. Meanwhile overgrazing is accelerating the progress of erosion.

It seems desirable that a special research project for the specific purpose of working out some system of protecting the Bad Lands and the Breaks and stopping the excessive erosion now taking place in these regions should be undertaken. It is an interstate and national problem, and seems to be one which could best be solved in a limited period of active study as a special project. This should not be primarily a forest project, but foresters should participate in the work. What is most urgently needed is some kind of vegetative cover to bind the soil, and regulated use to prevent its destruction when once established. This cover may be trees, brush, vines, or grass, whatever proves best. The Forest Service, through its experience in tree planting, its study of range plants, and its experience in practical range management, should be able to help in

working out some practical remedy for each region. The major objective of the project should be to work out some means of producing more favorable conditions for run-off control and reduction of erosion, and not necessarily for developing economically valuable products; it is possible, however, that products of use in industry would be realized later.

SUMMARY OF CRITICAL AREAS

Figure 6 shows graphically the location and extent of what are reported to be the most critical areas in the Mississippi Valley judged by their need of forest cover to prevent erosion or flashy run-off. These lands are divided into three classes, detrimental, neutral, and beneficial, according to the present condition of forest cover, and, as Table 7 shows, are located in 30 States.

TABLE 7.—*Extent of the Mississippi River Basin critical areas (gross)*

State	Influence on flood conditions				State	Influence on flood conditions			
	Detrimental	Neutral	Beneficial	Total		Detrimental	Neutral	Beneficial	Total
	Square miles	*Square miles*	*Square miles*	*Square miles*		*Square miles*	*Square miles*	*Square miles*	*Square miles*
Alabama	4,922	1,015		5,937	New Mexico			3,276	3,276
Arkansas	1,477	13,628		15,105	New York		308		308
Colorado	123	108	11,251	11,482	North Carolina	1,169	2,261	2,400	5,830
Georgia	31	569	615	1,215	North Dakota			133	133
Illinois	12,598			12,598	Ohio	8,845			8,845
Indiana	6,153			6,153	Oklahoma	16,551		677	17,228
Iowa	17,182		275	17,457	Pennsylvania	2,907	6,245		9,152
Kansas	1,538		218	1,756	South Dakota			2,966	2,966
Kentucky	13,244	10,890		24,134	Tennessee	12,706	7,399	1,907	22,012
Louisiana	2,446	154		2,600	Texas	292	3,599		3,891
Maryland		461		461	Virginia		3,184	446	3,630
Minnesota	5,538		1,056	6,594	West Virginia	6,676	12,613		19,289
Mississippi	10,798			10,798	Wisconsin	8,691	2,246	846	11,783
Missouri	15,844	9,967		25,811	Wyoming	46	62	18,443	18,551
Montana		277	18,227	18,504					
Nebraska	154		1,477	1,631	All States	149,931	74,986	64,213	289,130

Table 7 deals generally with forest lands and does not include either the Bad Lands or the Breaks, which are also included in this circular and recommended for special study. These areas are classified as detrimental treeless areas and embrace a total of 32,471 square miles distributed among certain Western States as shown in Table 8.

TABLE 8.—*Areas of Bad Lands and Breaks*

The Bad Lands		The Breaks	
State	Area	State	Area
	Square miles		*Square miles*
Colorado	31	Kansas	1,646
Montana	10,121	New Mexico	154
North Dakota	3,845	Oklahoma	3,861
South Dakota	1,507	Texas	11,306
Total	15,504	Total	16,967

These 32,471 square miles of critical treeless areas, added to the total of 289,130 square miles of critical areas based on forest requirements make a grand total of 321,601 square miles, gross, of critical areas out of a grand total of 1,231,492 square miles in the Mississippi watershed. This amounts to about 26 per cent of the entire watershed.

However, the only areas in which anything like 100 per cent of the acreages outlined are actually critical are the Bad Lands and the Breaks. These are not included in the following discussion, which applies specifically to areas where forests are a critical factor in run-off and erosion conditions.

Many of the areas are mapped as critical because they include a considerable percentage, usually 10 per cent or more, of lands on which the retention of forests or the restoration of forests is important to prevent flashy run-off and serious soil erosion. In some regions these lands are found in innumerable small tracts scattered throughout lands which are not critical. This applies particularly to the critical areas shown in States and localities which are primarily agricultural, and with special force to the critical areas as mapped in Illinois, Wisconsin, Minnesota, Iowa, and northern Missouri. In the region of greater forest-land density the proportion of lands actually critical in character within the areas shown as critical may run as high as 80 per cent or more. This applies particularly to the critical areas outlined in Louisiana and Arkansas, and in eastern Tennessee, Kentucky, West Virginia, and Pennsylvania.

The acreage actually critical is roughly estimated at 150,000 square miles, out of the gross critical acreage of 289,000. The acreage thus estimated as critical all comes within the broad classification of forest land, actual or idle, totaling 244,000 square miles for the entire Mississippi drainage. This leaves an estimated total of about 94,000 square miles of forest land in the valley having soil and topography of such characteristics that the presence or absence of forest cover has no marked influence on erosion or stream flow therefrom. The 150,000 square miles of critical acreage, added to the acreage in the Bad Lands and the Breaks, gives a total critical acreage of 182,471 square miles within the limitations of the study for the entire Mississippi Valley.

PUBLIC-DOMAIN GRAZING LANDS

With very few exceptions, each individual drainage unit which embraces any considerable acreage of unreserved public domain suitable for grazing is reported as being injured by overgrazing and unregulated grazing, with destructive erosion taking place over large areas. No data are available to show to what extent this results in increasing the rapidity of run-off. From a flood standpoint, except for local freshets, such increase would not be material. The burden of silt which misused grazing lands contribute to the Missouri and Arkansas must, however, in the aggregate be very great.

These lands are open to entry under the various public land laws, consequently the acreage is slowly dwindling. The total area of public lands in the Mississippi Basin, according to the report of the General Land Office of the Department of the Interior, July 1, 1926,

was 32,514 square miles, or 22,808,960 acres. Some of these lands are timbered, but practically all have some value for grazing. Most of these lands—31,084 square miles—are on the watershed of the Missouri River; 1,410 square miles are on the Arkansas watershed; and 20 square miles are on the Red River.

The managament of these lands for grazing purposes is a problem of control. It is lack of control and not ignorance or lack of interest that accounts for misuse. There is no incentive to any stockman to avoid overgrazing the public range when the leaving of any unused forage plants for reseeding is almost certain to result in some other stockman driving in his stock and feeding off what has been so painstakingly saved.

The regulation of such public grazing lands is one of the unsolved problems before Congress. It appears useless for the purpose of this study to attempt to determine definitely their quantitative contribution to the Mississippi floods or to try to prescribe a remedy. The range problem involves many complicated economic and political factors that are so far-reaching as entirely to overshadow their importance from a flood-control standpoint. It does, however, seem desirable to call attention to the fact that under present conditions they add to the difficulty of flood control and to advocate public-range control as recommended to Congress by the Secretary of Agriculture and the Secretary of the Interior.

FINDINGS OF FACT[5]

The outstanding facts brought out by the study of the relation of the forest land in the Mississippi drainage basin to the general problem of floods appear to be the following:

The forests of the Mississippi Valley never covered more than 40 per cent of the total area of the drainage basin.

By necessary human use and by unnecessary abuse and neglect this proportion has been reduced until it is now about 20 per cent, or about 244,000 square miles.

A very small part of this total area of forest land is in a virgin condition, the remainder being largely cut over, with 35,000 square miles so denuded of forest or other valuable growth as to be classified as "waste" or "idle" land.

About 115,000 square miles, of which 10,000 square miles are in the "idle" class, are in farm woodlands; and 129,000 square miles, of which 25,000 are "idle" or "waste," are within the commercial timberland class.

By reason of character of soil, topography, and precipitation, the character and density of forest cover on certain of these lands have a direct relation to run-off or soil erosion or both, and on such areas forest destruction increases torrential run-off and causes serious erosion. Areas with such characteristics were therefore classified as "critical areas."

The regions classified as critical areas on the Mississippi drainage amount to 289,000 square miles, of which, upon the basis of the present tendency toward increase or decrease in the ability to help

[5] Round numbers used generally.

prevent floods, 64,000 square miles were found to be beneficial, 75,000 neutral, and 150,000 detrimental.

The actual acreage of critical forest land within the regions outlined is about 150,000 square miles; and the approximate distribution by class is beneficial 35,000 square miles, neutral 40,000 square miles, detrimental 75,000 square miles.

With the exception of the lands within public forests and parks, amounting to 700 square miles in State ownership and 43,000 square miles gross in national ownership, the forests on critical areas are not contributing full service in the direction of flood control. This is due largely to injury by fires in commercial woodlands and to too heavy grazing in farm woodlands.

About 700 square miles of publicly owned forest lands in the Mississippi Basin adjoin existing national forests and are similar to them in character and importance from the standpoint of preventing erosion and regulating stream flow.

The adequate protection of the forests in the Mississippi Basin as recommended by the Senate Select Committee on Forestry and as authorized by section 2 of the Clarke-McNary law, would require an annual expenditure of $490,000 by the Federal Government and $1,470,000 by private owners and the States, making a total for the Mississippi drainage of $1,960,000 annually. The present (1928) expenditure by the Federal Government is $170,000, and by private owners and States $474,000.

The Upper Mississippi Wild Life and Fish Refuge area, which is being purchased by the Federal Government, safeguards the narrowing of the river overflow channel as far south as Rock Island, Ill., and is therefore a favorable factor in future stream-flow regulation.

In addition to the critical forest lands, 15,000 square miles of Bad Lands and 17,000 square miles of the Breaks (although treeless) should also be classified as critical areas because of their great contributions of silt to the Mississippi flood problem. The Bad Lands appear to be responsible for contributing an annual burden of silt aggregating 144 million tons, and the Breaks for contributing a somewhat smaller amount.

The loss of soil by erosion from cultivated fields is a serious menace not only to the channel of the Mississippi River, but to the permanency of profitable agriculture in many parts of the valley which has thus far flourished through the virgin fertility of rapidly eroding soils.

RECOMMENDATIONS

The foregoing findings of fact lead inevitably to recommendations for remedial action by the Government of the United States. This action would not take the place of levees, reservoirs, by-passes, or spillways as flood preventive measures. The action recommended is not in any way intended to minimize the necessity of such works but is supplemental thereto. The effect of such action on floods either as to volume or frequency will be slow in manifesting itself. It will be largely unrecorded for the reason that its significance will be largely in what does not happen under changed conditions but would have happened had the old order continued.

It should, of course, be understood that appropriations or expenditures are suggested or recommended only upon condition that they be made at such times and in such amounts as may be in harmony with the fiscal policy of the Government.

First in order of importance is the extension of fire cooperation under section 2 of the Clarke-McNary law. The blanket of organized protection should be extended to all forests on the Mississippi watershed as rapidly as the States and private owners are willing to undertake the work. Ultimate cost per year for entire watershed about $490,000. This includes all forest lands as well as "critical areas," for flood control, since it is impractical to attempt a definite separation into classes for protection purposes. This would be accomplished with the appropriations now authorized by the Clarke-McNary law.

Idle waste land on farms and submarginal land used agriculturally should be planted to forests under the Clarke-McNary Act as rapidly as the States and private land owners will expand such work and as cooperative expenditure will be in accord with the fiscal policy of the Government.

Instruction to owners of 115,000 square miles of forest land in farm ownership should keep pace with planting and need for advice in use and marketing forest products.

The purchase of about 2,642,000 acres of protection forest lands in national forest purchase units already approved and established by the National Forest Reservation Commission on the Mississippi watershed should be completed and in addition approximately 5,900,000 acres of protection forest lands adjoining two existing national forests in Arkansas and in 15 other units on the Mississippi drainage should be purchased. Inclusive of forest lands still to be acquired in completing units now approved under the Weeks law the total amount of land would be 8,542,000 acres. These purchases could be made under the provisions of the Weeks Act and Clarke-McNary Act during a period of from 5 to 10 years, subject to the appropriations authorized under the fiscal policy of the Government.

Protection and administration of present national forests, parks, and game refuges should be continued under present policies; and adjoining forested areas of unreserved public domain should be added to national forests.

Investigations of the Bad Lands and the Breaks should be authorized as a research project with a view to discovering some method of preventing serious erosion.

The plan of control of public grazing lands recommended by the Secretary of Agriculture and the Secretary of the Interior should be adopted. Expense, nominal appropriation to start. After starting activity will be self-supporting from fees.

Provision should be made for securing a permanent record hereafter of stream-flow measurements and silt content of the Mississippi River at some point below Cairo and on each of the principal tributaries entering the river below that point and data essential to a long-time study of land use and erosion remedies thereby secured.

CONCLUSIONS

If these recommendations are carried out, a reasonable effort will have been made to take advantage of the power of good forest cover to hold water and soil and thus to play its part in restraining the violence of floods and erosion. Just how great or how small this influence would be in a vast watershed like the Mississippi no one can ever say, for the forces involved are too vast and complex for measurement. Yet such quantitative measurements as are available, combined with the cumulative force of common-sense observation and circumstantial evidence, point clearly to the conclusion that this influence is too important to neglect.

The benefits of good vigorous forest cover do not end with their ameliorating effect on stream flow and silting. Keeping our forest soils in place instead of letting them waste away to clog our river channels, making those soils fully and perpetually productive—these objects in themselves justify large investments in protecting and restoring our forests. Such investments are financially sound because they will pay interest and dividends in timber products, and the resultant benefits in river protection will be a by-product without cost.

Forest rehabilitation is not urged as an alternative to engineering works for flood control. It is supplementary to the engineering program, but it is a supplement of such importance that no complete plan of flood control can omit it.

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